C. H. Hardin

NAVIGATION THROUGH THE AGES

A Handbook of the Exhibition

held by the Royal Geographical Society and the Institute of Navigation, showing the development of navigation from its beginnings to the achievements of the present day

TWO SHILLINGS AND SIXPENCE

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Navigation Through the Ages

NAVIGATION is the whole art of directing a vessel on its course, but when that course lies over the pathless sea, a distinction must be drawn between seamanship and navigation, which then becomes the art of finding the way. It is this absence of a visible path that has imparted to navigation something of its air of mystery. Even with a familiar coast line in sight, the navigator must take bearings of some sort, deduce his position from them and lay off a course: out of sight of land his deductions are from the distance he has already covered and his knowledge of where his destination lies. But the winds and currents are variable quantities which he can estimate imperfectly. When distance increases the uncertainty of such estimates he relies on yet more indirect methods of deducing his position, making astronomical observations and, today, maintaining radio contact with the land by instruments which interpret for him the paths of wireless waves.

From the simple and almost intuitive geometry of direction and distance the mathematical basis of navigation grew to include the geometry of the sphere, both for the observation of heavenly bodies and the laying down of courses on the round Earth on which the mariner sails.

Navigation today, with all the complexity of methods devised to meet the requirements of modern ships and aircraft, has not outgrown the simple tasks of fixing a position and laying down a course; nor is it divorced from the acts of handling the craft itself. As John Dee wrote in 1570: "The Arte of Navigation demonstrateth how, by the shortest good way, by the aptest direction and in the shortest time, a sufficient ship . . . be conducted".

The history of the sea takes us back very much farther into the past than any knowledge we now possess of early methods of navigation. No doubt pure seamanship is the older art and a sharp look-out was all the early seaman used, sailing familiar waters in sight of the land. But more distant voyages were made in antiquity: from Crete to Egypt, from Brittany to Ireland, from Aden with the monsoon to Malabar, and from Norway as far as Greenland and America; yet, of the skill and equipment that such voyages imply we have no certain knowledge.

It is tempting to speculate on astronomical methods that the old mariners may have used to fix their positions at sea, but we have only accounts of dead reckoning: 'from Carpathos it is 50 miles with Africus to Rhodes' we read, and 'from Paphos 3800 stades with Boreas to Alexandria'. Dead reckoning, still the most fundamental of the navigator's tasks, is the estimate of position from the distance made good in a known direction.

The earliest directions were named from the following winds, and the ancient Greek wind-rose distinguished 12 points. A 16-point system, possibly of Etruscan origin, was in use in medieval Italy and the set of bearings we now use was developed by the Norsemen.

The behaviour of the heavenly bodies was not, however, ignored before

NAVIGATION THROUGH THE AGES

A Handbook

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the days of the mathematician and the instrument maker; the Sun at noon, the winter, summer and equinoctial sunrise and sunset were known points of bearing to the Greeks. So we read 'from Delos 50 miles towards the summer sunrise to Icaros'. Also the Pole Star, though farther from the Pole than it is now, was known to mark the north.

Ancient achievements in mathematical astronomy, too, were considerable. The Greeks deduced the spherical form of the Earth and its approximate diameter, determining latitudes from the lengths of shadows. Yet it does not appear that this knowledge was used by the seamen of the day and it did not survive in the traditions of European navigation. The Portulan charts (see page 13) of the Middle Ages show a remarkably correct outline of the Mediterranean and rhumb lines mark the sailing courses, but no parallels or meridians.

The accuracy of the Portulan charts must be attributed to the coming into general use of the magnetic compass, though when and from what source it was introduced into Europe and used at sea remains unknown; it was certainly in use in the twelfth century A.D. It is difficult to judge the extent to which astronomical methods were used to determine position at sea before the Renaissance. The latitude of a place, its distance from the equator, can be calculated from the height of the Sun at noon or of any other star when it is at its highest, or from the height of the Pole Star. The longitude, or distance east or west from a chosen place, is more difficult to find. The daily rotation of the Earth, or time, provides a means of measuring this distance and until an accurate means of timekeeping was provided at sea the required latitude was first made and then the ship steered east or west to its landfall.

Astrolabes (see separate note on page 14) were available for measuring the altitude, and Chaucer wrote a handbook on their use, but it says little of their use at sea. The cross-staff was known too, in the thirteenth century at least, but neither instrument was accurate within half a degree, that is 30 sea miles, and it seems doubtful if they can have been a very valuable aid to navigation in the enclosed waters of the Mediterranean or even along the Atlantic shores of Europe.

A new age began with the long ocean voyages of the Portuguese and Spaniards. Now the familiar landmarks and courses of the old world fell astern; as it was necessary to supplement dead reckoning the old astronomical instruments were brought into regular use at sea. To the *Regiment of the North Star* (a table corresponding to the Pole Star tables of the modern NAUTICAL ALMANAC) was added the *Regiment of the Sun*, a table of the Sun's declination for use in tropical latitudes. Also Columbus on his first voyage in 1492 made many latitude observations with the Astrolabe and noted the variation of the compass from the true north.

By the sixteenth century most of the problems of mathematical navigation had presented themselves to the practical sailor and most of them had been, in some measure, solved. Treatises on navigation were now printed books, and these survive for us to see. John Davis's 'SEAMANS SECRETES', printed in 1594, shows what advances had then been made, for it covers most of the ground of a manual of the nineteenth century. In this book the "sailings" are distin-

guished and described: plane sailing, which ignores the curvature of the Earth, for computing the day's run; sailing by Mercator's chart, which makes the proper allowance for curvature and was introduced in 1564; and great circle sailing, too, for the most direct routes over the oceans. Tides are predicted from the "Establishment of the Port" and the age of the Moon; the latter found from the Golden Number of the year, the method still in the English Prayer Book "to find Easter Day".

Though Davis himself introduced the Backstaff, the improvement of instruments lagged behind; he says, "but the Sea Compass, Chart and Cross-staff are instruments sufficient for the seaman's use".

The perfection of the science, as seen in its broad outline by the Elizabethans, was the work of the next two hundred years. Newtonian mathematics and astronomy led to the construction of accurate tables; and to this end, and more particularly for the provision of Lunar Tables for longitude observations, the Royal Observatory at Greenwich was established in 1675. In 1698 Edmond Halley, in command of the *Paramour*, proceeded with her "on an expedition to improve the knowledge of the Longitude and variations of the compasse". The first chart of the magnetic variation was the fruit of his voyage, but did much to dispose of the hope that the variation of the compass would prove a practical method of determining longitude, for it had been supposed that the variation increased steadily as one went east or west from the Cape Verde Islands.

In 1714 Parliament passed an Act "for providing a publick reward for such person or persons as shall discover the Longitude". Many quaint solutions were put forward, but two emerged as prime contestants for the prize: the method of Lunar Distances and the Marine Chronometer.

The cross-staff gave place to the reflecting octant, the precursor of the modern sextant. Such an instrument had already been projected by Robert Hooke and by Newton but, in 1732, Hadley's instrument was tested at sea in the yacht *Chatham* and found serviceable—and, indeed, accurate to within a mile or so. In 1733 Hadley described to the Royal Society a quadrant with a bubble attached to its radius—the first of the bubble sextants. The new octants made possible the accurate measurement of Lunar Distances by which the seaman could discover the time at Greenwich Observatory corresponding to his own observations. The method itself had been suggested as early as 1474. In 1767 the first issue of the *Nautical Almanac*, based on the Greenwich observations, was issued, with requisite tables for finding longitude at sea to within one degree.

But meanwhile John Harrison had solved the problem of constructing a reliable clock to show Greenwich Time at sea; his first in 1735, and others, less cumbrous, in 1739, 1757 and 1759. The fourth was entered for the "publick reward" on a voyage to Jamaica in 1764 and found to comply with the conditions, though it was not until 1772 that he succeeded in establishing his claim before the reluctant Board of Longitude. A copy of this chronometer, made by Larcum Kendall, was carried by Captain Cook, on his second and third voyages. "Our error in longitude", says he, "can never be great so long

as we have so good a guide as Mr. Kendall's watch", and his charts show that he was right.

Other clock-makers applied themselves to the manufacture of chronometers in the large numbers soon in demand and Arnold and Earnshaw each produced more than a thousand; Earnshaw also invented the detent escapement in use today.

The more laborious and less accurate method of Lunar Distances was retained as a check on the chronometer performance and the necessary tables only disappeared from the *Nautical Almanac* with the world-wide dissemination of wireless time signals.

The accuracy of instruments continued to increase. Ramsden's dividing engine and Dollond's acromatic telescope made possible the construction of small precise instruments of metal in place of the earlier unwieldy wooden ones. The Reflecting Circle of the late 18th and early 19th centuries was intended for the better measurement of long arcs of lunar distance but fell into disuse with the improvement of the sextant itself and the extension of its arc to some 140° as at present.

The steamer is faster and holds to a more deliberate course than the sailing ship, which must be trimmed to the varying wind, and in the nineteenth century progress lay rather in more accurate methods of dead reckoning than in astronomy.

The most notable advance in astronomical navigation was provided in 1837 when Captain Thomas Sumner of Boston, making St. George's Channel in a storm, stumbled upon a principle that the astronomers had overlooked. A single observation of the Sun or a star, even when not taken to fix the latitude or longitude, does in fact give a line of position which can be laid down on the chart. The method of the Sumner Line, as improved upon by Marc St. Hilaire in 1875 is now in general use at sea; lending itself as it does to rapid observation and the use of convenient and time-saving tables, it is the basis of all astronomical navigation in the air.

The iron ships of the century set a problem to the compass makers. The compass, though it had seen its share of mechanical improvement, had to be redesigned and furnished with adequate means of compensation for the deviating magnetism of a ship's hull, on principles which were established by Sir George Airy, Astronomer Royal, in 1835. Lord Kelvin effected further important improvements in compass construction in 1876. The Gyro-compass, which is independent of the Earth's magnetic field and relies on the property of the freely spinning gyroscope to set itself parallel to the Earth's own axis of rotation, was first produced as a practical ship's compass in 1906.

Dead reckoning is an account of course and distance and, parallel with the improvement of the compass, came an increased accuracy of the measurement of distance. The log-ship and line was first described in 1587. A float, the "log-ship", falls astern of the moving vessel and the run of the line is timed with a sand glass, the "knots" showing the vessel's speed. Log-ship and line held the field until the middle of the nineteenth century when towing logs came in, Massey's being the first to achieve any reasonable degree of accuracy;

towed constantly astern the spinning log marks up the miles of the ship's run. Modern logs, either on a rotation or a pressure principle, provide an accurate measure of distance run, and today engine-room revolutions provide another measure of speed when due allowance is made for varying draught and state of the ship's bottom.

Modern charts are themselves an essential instrument of coastal navigation. Compass bearings and sextant angles to landmarks that are accurately laid down on the chart, provide reliable fixes of position in waters that are often full of dangers to the great ships of today. Soundings and the nature of the sea bottom are another aid for which the modern chart is specially designed. The hand line and lead were sufficient for a pilot feeling his way over poorly charted shallows, but Lord Kelvin's Sounding Machine of 1872, registering the pressure of the overlying water on a tube towed at the end of the line, first enabled soundings to be taken from a ship at speed. The echo-sounder, which times the course of a sound wave emitted from the ship and reflected back from the sea bed, is even more convenient in use and provides a continuous trace of the submarine profile. A glance at a modern chart or Pilot Book shows too the many fixed aids to navigation that have been installed along the seaways of the world: buoys, beacons, lighthouses and light-vessels. Perhaps the most noticeable difference between the old charts and the new are the abundance of soundings, both inshore and in the depths of the ocean, and the disappearance of the antique spiders-web of rhumb lines and ornate compass roses; their place is taken by the compass rose marked in degrees, to be used with the much simpler parallel ruler.

The nineteenth century may be said to mark the end of an era that began with the great voyages of discovery and to mark as well the dawn of another: the era of radio aids to navigation and of navigation in the air. Here the historical perspective in which we view the achievements of the past is lacking; our new problems are perhaps yet incompletely seen and the current solutions perhaps only tentative.

The invention of the flying machine did not a first present new problems in navigation for, with the ground in full view below, the pilot needed no more than a map to find his way in the air. As flight distances increased map reading was supplemented by dead reckoning, and here the special problems of air navigation began to be encountered. The allowance for the drift of the craft with wind and current which must be made at sea becomes of paramount importance in aviation, for, in anything but a flat calm, the track of an aeroplane is by no means the same thing as its apparent progress through the air. The mathematical problem is that of the triangle of forces: its three sides: the motion of the machine through the air, the flow of the air itself and, what the pilot seeks, the resultant movement over the ground. The first is given by the compass and Air Speed Indicator. The force and direction of the wind must usually be determined indirectly by solving the triangle in reverse, using a Drift Indicator, which, from sights to a fixed point on the ground, shows the divergence between the 'heading' of the aircraft and the direction of its real track. The graphical solution of the triangle of forces is facilitated by

Course and Distance Calculators. By 1914 simple air speed indicators, drift indicators, and a liquid filled compass that was reasonably steady had all come into use, and there has been much improvement in these essential instruments since. Altimeters, to show the aircraft's height, differ in no essential from the common aneroid barometer, but their graduation and the corrections to be made to their readings are based on new investigations into the physics of the atmosphere.

A fundamental difference between the ship and the aeroplane has meanwhile to be provided for. Flight is a motion in three dimensions and not only is it necessary for the pilot to know the 'altitude' of his machine: how far it is inclined in a climb or dive and how far it is banked in a turn: but this essential knowledge is not provided with sufficient reliability by instruments that depend on the behaviour of a plumb line or spirit level. The balance of forces that makes it possible for the aircraft to wheel and circle in the air sets a plumb line or level within it an at angle to the true vertical, vitiating any observations based on them and displacing the card of a compass from its true reading. The pilot's judgment may supply the deficiency when the earth's horizon is visible below him and the 'aperiodic' compass, introduced in 1918, is insensitive to small fluctuations of course that are not long maintained. But the gyroscope, unlike the plumb line, does maintain its direction in space except so far as it is affected by the friction of its bearings and the minute lack of balance unavoidable in its construction; gyroscopes have therefore been built into a whole range of aircraft instruments. For indicating the altitude and motion of the plane there are direction gyroscopes, angular velocity meters, and the gyroscopic artificial horizon; the gyroscope has also been used to stabilise the magnetic compass and remove the effect of tilt when the aircraft is banked.

The gyro compass as used at sea has not been found directly applicable to air navigation, and the directional gyro compass is therefore coupled to an accurate magnetic compass so that, stable in itself, in spite of the aircraft's motion, it indicates the *average* direction of the less stable magnetic instrument.

A battery of gyroscopic instruments of the kinds described, linked to the controls of the aircraft itself, forms the Automatic Pilot, which will hold the craft on its predetermined course, correcting each deviation more faithfully and untiringly than any human pilot can.

The astronomical determination of position became necessary, as at sea, when courses lay over the oceans, beyond the landmarks of the map. The marine sextant had been used in the air before 1919, but neither it nor the methods of calculating then current were well adapted to air navigation. The visible horizon becomes distant and indistinct at even moderate heights and the correction for its dip below the true horizontal becomes large and indefinite; and, without swift means of calculation, the position will be far astern before it has been worked out.

The decade 1919-29 which saw the first flying of the Atlantic saw also the main developments of astronomical navigation in the air. The first crossing was by flying boats of the U.S. Navy in 1919 by way of the Azores, but ships

were stationed at intervals of 50 miles to mark the way. In the same year Alcock and Brown flew direct from Newfoundland to Ireland using star and Sun sights, but as late as 1928 both Hinkler and Amy Johnson flew from England to Australia by map reading and dead reckoning alone.

Captain Baker's sextant of 1919 viewed the visible horizon in both directions, thus removing the uncertainty of its dip below the true horizontal, but the visible horizon is often the top of a cloud bank and, at night, no horizon is visible.

Meanwhile, bubble sextants had been introduced which require no reference to the visible horizon but are, like other instruments which incorporate a spirit level, affected by the false vertical of an unsteady aircraft.

Recent improvements to the bubble sextant have provided for the automatic averaging of a series of successive sights to reduce the error of the false vertical. But the enlistment of the gyroscope to remove this source of error has not so far proved successful.

More striking than the improvement of the sextant has been the development of new methods of calculation. Air Almanacs, the first produced in 1933, give the astronomical data in a more convenient though less precise form than the Almanacs used at sea. Shortened forms of compilation using special tables save time in laying down the Position Line derived from the observation taken, while Altitude and Azimuth Tables enable it to be laid down with almost no calculations at all. A defect remains: the less arithmetic the navigator is required to perform the more voluminous must his tables be. Mechanical devices to eliminate calculation have received much attention, but have not achieved great success, and a simpler solution may yet be found.

Air navigation is inseparable from meteorology, not only for warning of dangerous and unfavourable conditions, but for the basic information of wind and weather by which the pilot directs his course. It is a hundred years since Mathew Fontaine Maury mapped the prevalent wind systems of the world to determine the best courses for ships sailing across the oceans, and, in much the same way, the day to day pattern of the changing pressure systems of the air determines the most expeditious course to be flown.

But only half the tale of Air Navigation has yet been told. In the modern practice of aviation, the radio aids, which we next briefly consider, have overshadowed astronomical methods of position fixing and have largely supplanted all other methods in the close-range work of effecting a safe approach to an airfield and a safe landing. Indeed air navigation and the related problem of aircraft detection have been the prime incentives to the development of the new aids.

Geometry, Astronomy and the Earth's magnetism were the foundations of navigation in the past; there is something entirely new in the application of wireless waves to the finding of position and direction, for they provide a physical link between the vessel or aircraft and the distant beacons or landmarks by which it is navigated. The first beginnings of the new method are almost as old as wireless telegraphy itself. It was soon discovered that the direction from which a message was received could be distinguished by the

receiver, and bearings were taken on distant shore stations or the bearings of distant ships were observed on shore and reported back. Though still used, such bearings are far from exact, and their place is being taken by other radio aids to navigation developed during the war.

The new aids are legion and their names a maze of code words and initials, devised to cloak them in the secrecy appropriate to their military value. For simplicity they may be classified according to the use that is made of them. There are systems which provide a line of bearing, CONSOL (or SONNE); systems which fix the observer's position with respect to a set of stations on the ground, DECCA, GEE, LORAN, or to a single station, REBECCA, EUREKA; P.P.I. Radar systems which provide a picture of land, beacons and vessels even when they are obscured by fog or cloud. There are also systems which assist or control an aircraft's approach and landing irrespective of weather and visibility: ACR and GCA in which the approaching aircraft are observed by instruments at the aerodrome and instructed by telephone what to do: BABS and ILS in which the pilot aligns his machine on beacons that mark the runway. Some only of the systems named are strictly 'radar', which may be defined as the detection of the infinitesimal time-lag between radio signals that have followed paths of different length; others depend on the interpretation of the mingled pattern of waves received from a set of distant transmitters.

The complexity of the new instruments defies any simple explanation, but it may be well to select a few and describe briefly what they do. There is a chain of DECCA transmitters in this country, a set of three interconnected stations radiating a pattern of waves in the ether not altogether unlike the pattern of ripples you would get by throwing three pebbles into a pond; the pattern is one of diamond-shaped intersections. The receiving apparatus on board ship is essentially a counting machine to count the number of complete 'diamonds' between the ship and the transmitters and the odd fraction of the diamond in which the ship is situated. The count is displayed on the dials of the instrument and the position is plotted by the navigator on a chart, over printed with a "lattice" to show the pattern. GEE, though based on a different electrical principle, is used with charts overprinted with a similar lattice pattern.

P.P.I. (plan position indicator) is the Radar display on which the echoes of pulses transmitted from a ship or aircraft are displayed before the navigator. The instrument resembles a television screen and on it the echoes make points of light. The points lie in the same direction from the centre of the screen as the objects from which the echoes are received (for the pulses are emitted successively in all directions from a revolving aerial on the mast) and at a distance from the centre proportional to the distance of the object (because of the infinitesimal time-lag). The result is a veritable map on which not only the shore and the ship's position can be seen, but the position of other ships as well. It has proved invaluable for inshore navigation in fog and by unlighted coasts.

In the air, aids like H_2S furnish a map of the ground below the plane in which land is sharply distinguished from water and towns stand out from the general features of the land—an aid to navigation indeed and a deadly offensive

weapon of Bomber Command.

BABS, the Beam Approach Beacon System, is for assisting aircraft to land in poor visibility. The beacon on the ground is installed in a truck which takes up a position at the end of the runway. The signals it emits appear on a screen (again like the screen of a television set) in the cockpit as a thick 'dash' superimposed on a narrow 'dot'. When the dot and dash are of equal length the aircraft is on the line of the runway, when they are unequal it is off course to the left or right. The distance of the picture from the bottom of the screen shows the pilot his distance from the near end of the runway. In ILS (Instrument Landing System) the pilot's instrument is a dial with two moving pointers and a central mark. According to whether the pointers cross each other above or below, to the left, or to the right of the mark, the aircraft is heading off the runway or flying too high or too low.

From these many devices, developed within a few years for the special needs of war, one can but guess the place that the new methods will take in the navigation of the future. It is certain that no finality, either in design or application, has yet been reached.

CATALOGUE
of the
EXHIBITION

PORTULAN CHARTS

No date can be assigned to the first portulan chart. The earliest fragment, an imperfect sketch of the coast from the mouth of the River Maas to Acre in Palestine, is included in the eleventh century text of the *Ecclesiastical History* of Adam of Bremen. The earliest dated portulan chart (1311) is that of Petrus Vesconte, but without doubt it embodied the experience of many generations of ship masters.

The complete absence of earlier dated examples is a matter of no surprise, for in all probability these charts were secret documents providing information which their owners had no wish to divulge; moreover they were liable to wear and tear and to be destroyed when a new chart was purchased. It is significant that those which survive appear for the most part to have been drawn specially for presentation to Kings and Princes. Further it is unlikely that the production of these charts on a multiple scale began before the end of the thirteenth century.

The earlier portulans were made of sheepskin; later they were drawn on vellum. The change from one to the other was a gradual process and probably took place during the second quarter of the seventeenth century.

The most noteworthy characteristics of the portulan chart are the carefully delineated coastlines and the network of *loxodromes*—straight lines in the directions of the principal points of the compass and regularly distributed over the chart, the major intersections on the later examples being elaborately illuminated. Almost all these charts are orientated to the north.

In contrast with the fantastic representation of the interiors of continents on Medieval World Maps, the rudimentary portulan chart is remarkable for its disregard of land details. The inclination of the draughtsmen of later portulan charts to fill the continental interiors with mythical rulers and strange beasts, was occasioned and furthered by the fact that during the fifteenth century both the Catalans and Italians were drawing circular world maps.

The contribution of the portulan chart to the development of cartography, lies in the improvement in the delineation of the coastline on maps generally during the early sixteenth century.

1. Portulan chart on sheepskin of the Mediterranean, and Eastern shores of the Atlantic, from the British Isles to the Canary Islands. By Arnaldo Domeneth, an early chart maker of Catalan origin and follower of Petri Roselli. Drawn at Naples in 1486.
2. Portulan chart on sheepskin of the Mediterranean and Eastern shores of the Atlantic, from Iceland to Cape Verde Islands. By Vesconte Maggiolo (or Maiollo), a Genoese, who in 1519 became a *Magister cartarum pro navigando*, and appears to have founded a line of chart makers. Drawn at Genoa in 1548.

3. MANUSCRIPT ATLAS by Battista Agnese. Agnese produced many finely decorated atlases based on marine charts for the libraries of the wealthy. Such works were soon afterwards superseded by atlases of engraved plates. (*c.* 1550).
4. PORTUGUESE MS MARINE CHART of North Atlantic. The anonymous cartographer has followed to some extent the map by Lopo Homem of 1554. (*c.* 1555).
5. PORTULAN CHART on vellum of the southern part of the British Isles, the coast of France and the north coast of Spain. Signed "Thomas Hood made it 1596".
6. PORTULAN CHART on vellum of the British Isles and the coast of Europe from Cape Finisterre to Norway. The chart is mounted on four hinged oak platts. By Nicholas Comberford "dwelling at the signe of the Platt neare the west End of the Schoole House in Ratcliffe". 1666.
7. FASCIMILE OF BEHAIM'S GLOBE. The original globe, which is in Nurnberg, is probably the oldest terrestrial globe in existence.

   Martin Behaim (1459-1507) was a German astronomer and map maker who came to Portugal probably in the year 1484 and soon after his arrival made one or more voyages down the West Coast of Africa.The globe was made in 1492, the same year that Columbus sailed for America. It shows clearly the geographical information available to Columbus at that time. Marco Polo's discoveries in the Far East, two centuries earlier, are shown as also is the route round the Cape. America appears as numerous islands. The only meridian is drawn from pole to pole 80 degrees to the west of Lisbon. On the globe are drawn 111 miniatures, 48 flags, 15 coats of arms and over 1,100 place names.

ASTROLABES

Astrolabes are of Greek extraction, having been devised by Hipparchus in 150 B.C. They were much used by Indians, Persians and Arabs before they were introduced to Europe, where they first appeared in Spain, being brought there by Arabian conquerors in the tenth and eleventh centuries. Arabian astrolabes continued to be used in Europe until the end of the sixteenth century.

They seem to have first appeared in England about the beginning of the twelfth century, as a treatise on astrolabes, *De operatione Astrolabii*, was written by one Adelard of Bath, probably in the early forties of that century. The best known work on this instrument was the *Treatise on the Astrolabe* written by Geoffrey Chaucer in 1387 for the benefit of his 10 year old son "little Lewis".

Astrolabes were adapted for use by mariners in 1483 by Behaim, a celebrated German astronomer during the reign of King John of Portugal—the successor to Prince Henry the Navigator.

The uses of the astrolabe were many: they included the ascertaining of latitude, determination of time (both by the Sun and the stars), and measuring heights of buildings and mountains. They were also much used in the casting of horoscopes. In Eastern instuments the altitude of the Sun as it crosses the azimuth of Mecca is sometimes shown.

The astrolabe is really a celestial globe pressed flat, or, in more technical language, a stereographic projection on the plane of the equator. The rotating *Rete* or *Spider* shows by means of pointers the positions of certain important stars, and the ecliptic or Sun's path can be seen passing through the constellations. The stationary plate, beneath the *Rete*, represents important phenomena relative to the place of observation, e.g. the horizon, zenith, and circles of altitude &c. Heights of buildings etc. are computed from a scale on the face of the instrument, known as the *Umbra recta* and *Umbra versa*.

8. Mariner's astrolabe. This instrument was found under a rock in 1845 in the island of Valencia, Ireland. Three vessels of the Spanish Armada are known to have been wrecked near this spot and it is supposed that the instrument belonged to one of them. It was at one time the property of Robert John Lecky.

9. Astrolabe. An English Astrolabe of Spanish workmanship known as "John Thornoe's astrolabe". One plate only, for latitudes 51° 34′ (London) and 52° (Oxford). The two Latin inscriptions (one on the rule and one on the alidade) when translated read "A gift from Master Thornoe" and "Here lies the whole Universe in a Plane. Render thanks then to Ptolemy the pioneer of Scientific Studies". No Maker's name. (*c.* 1450).

10. Fore-staff or cross-staff. Invented by Levi ben Gerson, a learned Jew of Bañolas in Catalonia. 1342 A.D. These instruments were not, however, in common use by seamen till early in the sixteenth century. There is no mention of it by Columbus, Vasco da Gama, or Cabral; all of whom navigated by means of an astrolabe and quadrant.

The sketch shows how it was used. It shows only one transom or cursor, but as many as four were fitted to some instruments. The obvious disadvantage of this instrument was temporary blindness caused by the observer getting the sun in his eye, although shades of some kind were doubtless sometimes used. It was superseded by the Back-Staff. The Cross Staff shown is inscribed 'Hammon à St. Malo 1687'.

RING DIALS AND ASTRONOMICAL RINGS

The earliest form of ring dial, dating back to about 1400, was a wide ring with a fixed pin hole nodus drilled through it. The Sun's ray passing through this hole showed the time on the hour lines marked by sloping or curve lines, representing the seasons, on the inside of the ring.

This was later improved by drilling the nodus through a band of metal that moved in a groove round the ring and was adjusted to the time of the year. This enabled the hour lines to be drawn straight and with greater accuracy. These dials were used up to the eighteenth century but were confined to one latitude only.

In 1534 R. Gemma Frisius produced the "Astronomical ring" or "Universal dial" with which the apparent time of day could be found anywhere in the world. This instrument consists of two hinged metal rings set at right angles to each other, one representing the meridian and the other the equator. In the position of the polar axis is a slotted plate in which slides a block with a pin hole in it. When the dial is orientated, the meridian set to the latitude and the pin hole to the declination, the rays of the Sun passing through the pin hole will fall on the hour engraved on the equatorial circle. The whole instrument folds flat.

The accuracy of the ring dial is limited, and at sea, even under good conditions, it is probably liable to errors of half a degree (30 nautical miles) in latitude. Similarly, errors in time would be appreciable at sea owing to the difficulty of ascertaining the meridian accurately.

11. Astronomical ring. The instrument is made of brass and is 6 inches in diameter. The month scale is divided every 2 days and the hour scale every 5 minutes. The declination scale reads to the nearest degree. This dial can also be used

for observing the Sun's altitude. A pin is placed in the hole 45° from the pole and, with the latitude set at 0°, the instrument is suspended and trained on the Sun. The shadow of the pin will then indicate the altitude. By Dollond, London. Eighteenth century.

12. RING DIAL. Brass ring dial with adjustable pin-hole nodus. The month scale is crudely and inaccurately marked. Constructed for latitude 57°N (approx.). No maker's name. Probably British, sixteenth century.

13. NOCTURNAL. Nocturnals were first made about 1520 and were probably fairly commonly used during the 17th and 18th centuries. They were designed for telling the hour of the night by observing the positions of certain fixed stars, relative to the Pole star; these Stars were either the bright star in the Little Bear (γ Ursae Minoris) or the pointers of the Great Bear. The Pole Star was viewed through the aperture in the centre of the instrument and the long arm set to the selected star or stars.

    This particular instrument is made of boxwood and is for use with both Bears. On the back of it is a table showing the distance of the Pole Star above or below the pole for every point of the compass which the stars concerned bear from the Pole Star. English origin *c.*1700-1730.

14. SIR FRANCIS DRAKE'S SILVER MAP OF THE WORLD. The eastern and western hemispheres have been engraved or stuck on either side of a thin circular plate of silver, seventy millimetres in diameter. The track of Drake's voyage of circumnavigation, 1577-1580, is marked by a dotted line and illustrated by three small pictures of the *Golden Hind.* The hemispheres are beautifully and exactly delineated, and as many as 110 geographical names are given as well as eight inscriptions referring to Drake's voyage. The name of the artist is unknown but the world map bears a striking similarity to that by F.G., the initials hiding the identity of the engraver of the map illustrating the edition of Peter Martyr's *De Orbe Novo,* published by Hakluyt in Paris in 1587. Some half dozen examples of this silver medallion survive today: one, Sir Francis's own, at Nutwell Court, two in the National Maritime Museum and two in the British Museum. This silver map is thought to have been made between 1581 (the year Sir Francis was knighted) and 1585.

15. DRAKE'S DIAL. This compendium is more usually, and erroneously, known as Drake's Astrolabe. It was made for Sir Francis by Humphrey Cole in 1569, the year before his first expedition to the West Indies. Subsequently it came into the possession of the Stanhope family, who presented it to William IV, who gave it to the Royal Hospital at Greenwich. It is now in the National Maritime Museum. The dial is made of gilt brass and the covers are highly decorated with various figures including scholars with asses' ears, squirrels and peacocks. Seven dials are contained within the case. They are as follows:
    - i. A dial for finding the time of high water, or "an instrument to knowe the ebbes and fluddes". This operates in conjunction with:
    - ii. A table of "principal portes and havens" with the compass bearing of the Moon when the "sea is full" at each particular port.
    - iii. A circumferenter, with compass, alidade, and geometrical square.
    - iv. An equatorial dial with hinged gnomon and latitude adjustment.
    - v. A table of latitudes of places in the British Isles and Europe. London is shown as 51° 34 N, i.e. about 3 miles too far north.
    - vi. A perpetual Calendar for determining 'y Saint' daies & moueable feastes'.

vii. A dial showing the course of the Sun through the Signs of the Zodiac, the phases of the Moon, and aspects of the planets.

16. BACK-STAFF. Invented by Captain John Davis, the famous navigator and explorer, about 1590. These were in general use by mariners until superseded by Hadley's quadrant in the first half of the eighteenth century. The shade vane on the small (60°) arc is set to 10° or 20° below the estimated altitude of the Sun. The sight vane is then adjusted until the horizon is seen through the horizon vane slit at the same time as the shadow of the shade vane falls on the same slit. The sum of both arc readings is the apparent zenith distance of the Sun. The instrument exhibited has an improvement in the shape of a lens which projects a bright spot on the horizon vane instead of a shadow. It was made by Will Garner for Oliver Thompson in 1734.

17. CROSS-BOW. A somewhat cumbrous improvement on the back-staff, whereby the latitude can be read off direct and in one reading by observing a meridian altitude. To find the latitude, the upper or shadow vane is set to the declination and then as with the back-staff, the lower sight is moved along the arc until the horizon line is seen to coincide with the shadow of the upper vane. The cross-bow was also used to obtain the altitude of the Sun and stars by "fore" observation and of the former by "back" observations. The altitude scale is on the back of the instrument, and for "fore" observations the eye is placed in the centre of the instrument. The instrument shown is a model of one by Edmund Gunter in 1624.

18. GUNTER'S QUADRANT. Invented by Edmund Gunter, Professor of Astronomy. *c.*1618. A stereographic projection on the plane of the equinoctial. This instrument solves many problems, *e.g.* the Sun's right ascension, declination, meridian altitude and azimuth on any day. Also the hour of the day can be found by the Sun, and the hour of the night by any one of the five selected stars engraved on the face. This particular instrument was made by John Prujean, Oxford. *c.*1670.

19. ARMILLARY SPHERE. Constructed according to the Copernican theory. Brass, with the Sun in its centre. A bracket carries the Earth and Moon, and discs attached to circles revolving round the Sun indicate the following planets: Mercury, Venus, Mars, Jupiter and Saturn. Two fixed rings represent the Equinoctial and Ecliptic: the latter having the signs of the zodiac and months engraved upon it. French origin. 18th century.

20. ARMILLARY SPHERE. Constructed according to the Ptolemaic theory. Brass with a compass in the base on which the points are indicated by winds. At the centre of the sphere the Earth is surrounded by the orbits of the Sun and Moon, (the latter with its phases). The Arctic and Antarctic circles are shown as also are the Tropics of Cancer and Capricorn, the Equinoctial and Ecliptic: the figures of the zodiac on the latter being inlaid. Four stars (one of which is missing) are shown. A movable arc for latitude and declination is attached to the Meridian. By Antonius Costa Mirandulanus, 1676.

21. HAND GLOBE. A 2¾ inch terrestrial globe showing Drake's voyage round the world (1577-1580), also the trade winds. The sharkskin case is lined with a representation of the celestial sphere. By C. Price and I. Senex, Geographers. *c.*1740.

22. HAND GLOBE. A 2¾ inch terrestial globe showing Anson's voyage round the world, (1740-1744), also the trade winds. The sharkskin case is lined with a

representation of the celestial sphere. By G. Adams, No. 60 Fleet Street, London. *c.*1760.

23. HAND GLOBE. A $2\frac{3}{4}$ inch terrestial globe showing three voyages:—
    i. Anson, voyage of circumnavigation (1740-1744).
    ii. Cook's 3rd voyage in 1776, until his assassination in the Sandwich Islands in 1779.
    iii. The return voyage of Captain King, who succeeded Cook, in 1780.

    The sharkskin case is lined with a representation of the celestial sphere. By Dudley Adams, London. *c.*1796.

ALMANACS AND TABLES

This section throughout the different periods is devoted to a brief survey of the development of almanacs, containing the fundamental astronomical data, and the tables (or graphs) required to assist in the elaborate calculations by which the navigator's observations can be translated into geographical positions. The advances made in other directions—in our knowledge of the positions and motions of the heavenly bodies, in the invention of the sextant, in the development of the chronometer and in the technique of drawing position lines—are clearly reflected in the almanacs and tables, but the increasing speed of transport is also recognised by the constant improvement in the technique of presenting numerical data; the emphasis on this aspect is greatest for air navigation, but it is a dominant factor in surface navigation. Brief notes are given with the individual exhibits, but no attempt is made to explain more than their general purpose or main method—this is a specialist field, depending largely on detailed considerations.

24. REGIOMONTANUS: *Ephemerides astronomicae, ab anno* 1475 *ad annum* 1506: Norimbergae, 1474. One of the earliest "almanacs" to be printed; it also contains the principle of the determination of longitude by lunar distances.
25. COPERNICUS (NICOLAUS): *De Revolutionibus orbium coelestium libri vi*: Norimbergae 1543. The famous enunciation of the Copernican theory of the solar system, which is the foundation of all subsequent astronomy and navigation.
26. GUNTER (EDMUND): *Works* . . . fourth edition, enlarged by W. Leybourn, London, 1662. This collection contains the *Canon Triangulorum*, first published in 1620, which forms the basis of all the modern "short" methods of solving the astronomical spherical triangle. It also includes the "description and use of his sector, cross-staff, bow, quadrant and other instruments" first published in 1623.
27. CONNAISSANCE DES TEMPS for the year 1758. Paris. This was the first national ephemeris to be published. In this period neither instrumental equipment nor astronomical knowledge were adequate for more than a rough determination of latitude, and for the crudest determination of longitude from the eclipses of Jupiter's satellites etc.

Three independent events now revolutionised the theory and practice of navigation: first the invention of the sextant, generally associated with Hadley's paper to the Royal Society in 1731: secondly, the successful construction of the chronometer by Harrison in 1757; and, finally, the publication by Tobias Mayer of his tables of the motion of the Moon in 1753. They heralded the enormous

advances of this period, in which the foundations of modern navigation were firmly sown.

28. Maskelyne (Nevil)—*British Mariners' Guide*; London, 1763. A precursor of the official almanac published under his guidance a few years later.
29. The nautical almanac for 1767; London. For the first time are published the "lunar distances" used for the determination of longitude up to the early years of the present century.
30. Maskelyne (Nevil): *Tables requisite to be used with the Nautical Ephemeris for finding the latitude and longitude at sea*: London, 1766. With this publication, the Astronomer Royal provided the seaman with the first complete astronomical and tabular equipment for the determination of position.
31. Bowditch (Nathaniel): *The improved practical navigator; containing all necessary instruction for determining the latitude by various methods . . .*; Boston, 1773.
32. Norie (John William): *A complete set of Nautical Tables . . .*; London, 1803.
33. Inman (James): *Nautical Tables designed for the use of British Seamen*; London, 1835. The above are the three best known—all are in use in modified form today—of the many excellent collections of nautical tables published during this period.

BOOKS ON NAVIGATIONAL SUBJECTS

39. Navigation manual. By Battista Testa Rossa. 1557.
40. The cosmographical glasse. The first original English work on cosmography. By William Cuningham, London, 1559.
41. The rutter of the sea . . . with a rutter of the north. This book of sailing directions was first published in 1555 and was translated from the French by R. Copland. By Pierre Garcie, London, *c.*1560.
42. A regiment of the sea . . . and mariner's guide. A navigation manual first published in 1574. The Mariner's Guide explains the use of the plane chart. William Bourne, London, 1596.
43. The safegarde of saylers or great rutter. Translated out of the Dutch into English by Robert Norman. London, 1590.
44. The seamans secrets. By John Davis, 1657.
45. The coasting pilot. Sailing directions for the coasts of England, Flanders and Holland. London, 1672.
46. Idea longitudinis. By Lieutenant Edward Harrison, 1696.
47. A pocket book containing several choice collections of astronomy . . . navigation . . . &c. By John Seller, Hydrographer to the King. *c.*1710.
48. Astronomia accurata, or the royal astronomer and navigator. By Robert Heath, a Military Officer. 1760.
49. Elements in navigation. Manuscript by Commander E. H. Ensor while a pupil at the Royal Mathematical School, Christ's Hospital. *c.*1850.

ORIGINAL PLANS AND CHARTS

50. Original plans. Guernsey, Alderney, Serk and the Caskets. Two plans on one sheet, also a view of the Caskets and sketch of the "Marine Surveyor" in operation. By H. D. Saumarez, 1737. Dedicated to His Royal Highness Prince William Augustus, Duke of Cumberland. The signature of William Bligh appears at the bottom.

51. "River st. laurence, from green island to cape carrouge", with inset plan of the "Bason of Quebec". By James Cook, 1760. Dedicated to the Rt. Honble. the Lord Colville, Rear Admiral of the White Squadron of H.M. Fleet. (Quebec surrendered to the English the year previously).

52. Portsmouth harbour and entry. By Lieutenant Murdoch Mackenzie, 1782.

53. Original chart. Discoveries of H.M. Ships "Resolution" and "Discovery" on the coast of Asia and America in search of a communication between the Pacific and Western Ocean. By William Bligh, Master of the "Resolution", 1778-1779. Under the command of Captain J. Cook. (This is the same Captain Bligh who ten years later commanded the "Bounty".)

55. Telescope. The body and its five draw tubes are made entirely of paper. The third draw tube is signed "Ao. 1645-6. M.R."

Details are as follows:—

Length closed	$22\frac{7}{8}$ inches
Diameter of body	2 ,,
,, ,, object glass	$1\frac{3}{8}$,,
,, ,, eye lens	$1\frac{1}{4}$,,
Focal length	6 feet 6 inches
Weight	$18\frac{3}{4}$ ounce

By Maria de Rheita, 1646. This is the earliest known dated optical instrument in the world.

56. Telescope. The body is made of brass and covered with white shagreen. Four brass drawn tubes.

Measurements are as follows:—

Length closed	12 inches
Diameter of body	$1\frac{3}{4}$,,
,, ,, object glass	$\frac{7}{8}$,,
Focal length	3 feet 2 inches

By John Cuff, London. 1736.

57. Telescope. This telescope was originally the property of John Scott, Esq., R.N., public secretary to Lord Nelson, and who was killed with him at Trafalgar. It also saw service in the 1914-1918 war. By "Josh. Mazzuchi."

58. Telescope. Pocket Gregorian telescope made of brass. This is a reflecting telescope; the type first conceived by Dr. James Gregory in 1663. The rays are reflected through the eye-piece by a small concave mirror in the centre line of the instrument, which is attached to a small focussing screw fitted alongside the barrel. This particular instrument has a shaped shark skin case. The maker is unknown. *c.*1770.

59. Telescope. Formerly the property of Admiral of the Fleet, H.R.H. the Duke of Edinburgh (1844-1900). By G. Lee & Son, Portsea and Southsea. 1876. Presented to the National Maritime Museum by H.M. Queen Mary.

60. Telescope. A spy glass made of brass, with eight drawn tubes. Length extended 4 inches. Presented by Napoleon to Captain Stanfell, R.N., of H.M.S. "Conqueror" at St. Helena in 1818. Maker unknown.

61. Telescope. A night glass, formerly the property of H.M. King William IV. By Dollond, London. Presented by H.M. Queen Mary to the National Maritime Museum.

HADLEY'S QUADRANT. This is, strictly speaking, an octant, being one eighth of a circle, but due to the double angle of reflection the arc reads to 90° and it is generally known as a quadrant and is named after its inventor, John Hadley, in 1730.

The earliest models of this instrument were generally fitted with an 18 inch index arm, but later they were reduced in size. The third mirror, not present in the sextant of today, was for taking "back" observations and was used when there was not an open horizon for "fore" observations. When back observations were being taken the shades were moved from their normal position to the slot between the fore and back horizon glasses.

62. HADLEY'S QUADRANT. Ebony frame, 12 inches radius, ivory arc cut to 95°. The vernier (reading to minutes) reads from right to left as in modern sextants; it is actuated by a tangent screw. Beneath the frame is an adjusting screw connected with the horizon glass for correcting index error. By Spencer Browning & Rust. *c.*1780.

63. HADLEY'S QUADRANT. Mahogany frame 18 inches radius; ivory arc cut to 95°. The vernier (reading to minutes) is divided in the middle and reads from the middle to the right and from the left to the middle. Later models have verniers reading from right to left as they do today. By Benjamin Cole, London. *c.*1750.

64. HADLEY'S QUADRANT WITH BUBBLE ATTACHMENT. This was an invention of Hadley's, in 1733, to enable altitudes of the sun and stars to be taken when the horizon was obscured. The back horizon glass and sight vane have been removed and a brass frame carrying a level fitted instead. The bubble of this level is reflected through a lens to the eye by means of a special mirror. By Benjamin Cole at Ye Orrery, Fleet Street, London. *c.*1760.

65. KENDALL'S FIRST MARINE TIMEKEEPER. This machine was made by Larcum Kendall in 1769. It is a close copy, except for very minor details, of Harrison's fourth chronometer, and was made to the order of the Board of Longitude, to whom it was delivered in 1770. It was first tested at Greenwich and was then sent to sea with Captain Cook on the second of his three famous voyages. It performed extremely well under the very severe conditions of tropical heat, antarctic cold and gales to which it was subjected, and won high praise from Cook, who described it as "our never failing guide, the Watch". The instrument was also taken by Cook on his third voyage and was used by Vancouver in his famous survey of the north-west coast of North America. Lent by the Admiralty.

66. MARINE CHRONOMETER. A small chronometer (No. 356) by John Arnold, *c.*1796. It has an Arnold type brass-steel compensating balance, but an Earnshaw pattern spring detent escapement has been fitted at some later date. A going barrel is fitted in place of a fuse.

67. MARINE CHRONOMETER. A small chronometer (No. 512) by Thomas Earnshaw, *c.*1794. Fitted with Earnshaw's spring detent escapement, steel balance spring with bi-metallic compensating balance (brass fused with steel as in modern chronometers). To Earnshaw must be given the credit of evolving the chronometer which is all to intents and purposes the same as in use today.

68. MARINE CHRONOMETER. Marine Chronometer No. 23 by John Arnold. *c.*1790. This is one of this well known maker's early chronometers, with the Arnold type spring detent escapement and compensating balance.

69. QUINTANT. Brass gilt frame, 5 inches radius, with silver arc cut to 148°, vernier

fitted with tangent screw, reading to 30 seconds. Formerly the property of Capttain Wilkinson, R.N., who served as Lieutenant in H.M.S. "Goliath" at the battle of the Nile, and as First Lieutenant of Lord Nelson's flagship, H.M.S. "Elephant" at Copenhagen. By Berge, London, late Ramsden.

70. QUINTANT. This instrument is specially adapted for artificial horizon work. 1894.

SEXTANTS

The sextant is an improvement on Hadley's "Quadrant" as it is capable of taking angles up to 120° as opposed to 90°. The first person to extend the arc by 30° was Captain Campbell, of the Navy, in 1757, and except for variations in size, subsequent marine sextants have followed the original model very closely.

71. SEXTANT. Brass frame, 12 inches radius, and arc cut to 135°. Vernier, fitted with tangent screw reading to 30 seconds. (Horizon glass defective). This belonged to Admiral Sir J. T. Duckworth, K.C.B., Bart (1748-1817) who forced the Dardanelles in 1806 in an endeavour to prevent the Turks from joining Napoleon. By Nairne and Blunt, London. *c.*1760.

72. SEXTANT. This 6 inch sextant is made of white metal and silver and was the property of King Edward VII when he was Prince of Wales. By Mrs. Janet Taylor, 104, Minories, London. Presented to the National Maritime Museum by H.M. Queen Mary.

73. POCKET SEXTANT. Brass frame, 1¾ inches radius, with a silver arc cut to 130°. Vernier, fitted with tangent screw, reading to minutes. This instrument was used for many years by Sir William Gell (1777-1836) classical archaeologist and traveller. By "Fraser, Mathematical Inst. Maker to His Majesty, Bond Street, London". *c.*1780-90.

74. POCKET SEXTANT. Brass, 2 inches radius. Vernier, fitted with tangent screw, reading to minutes. Formerly the property of Sir Allen Young who, as Sir Francis McClintock's navigating officer in the "Fox" discovered McClintock's Channel in 1857, while searching for Sir John Franklin. Probably used during sledging operations. By Cary, London. *c.*1850.

75. ARTIFICIAL HORIZON. Used in connection with an observing sextant or theodolite when taking astronomical observations on land. Also pot containing mercury. Formerly the property of Admiral of the Fleet, H.R.H. the Duke of Edinburgh (1844-1900). By Elliott Bros., 101 St. Martin's Lane, London. 1861. Presented to the National Maritime Museum by H.M. Queen Mary.

76. REPEATING CIRCLE. The Mayer reflecting circle was improved upon by De Borda, Troughton and Mendoza de Rios, *c.*1800, and became a repeating circle. This instrument differs from the reflecting circle in that the central and horizon indices are independent. Angles are observed in the same way as with a quadrant or sextant, and are repeated as many times as may be required.

The instrument exhibited is fitted with an arc and two stops, originally suggested by Troughton. This is for fixing the indices at their proper angles when taking successive observations. It formerly belonged to the Rt. Hon. Sit George Cockburn, who was the First Naval Lord from 1841-6, and Admiral of the Fleet and Rear Admiral of the United Kingdom in 1851. By Thos. Jones, Charing Cross, London. *c.*1800.

77. REFLECTING CIRCLE. These instruments were invented by Professor Mayer of Groningen, and were designed principally for the observation of lunar distancee from the sun and stars. With it, angles may be observed up to 160°. Separate

readings (on each branch of the index) are taken of each observation, the plans of the instrument is then reversed and the three readings taken again. The mean of all six is the true apparent distance. The advantages of the circle over the sextant, besides its capability of measuring a much greater angle, are that it entirely cuts out index error and errors due to any faults in the graduation of the arc. Side error, perpendicularity, and errors due to the coloured shades are almost entirely eradicated also. The instrument exhibited is made of brass with a silver arc of 5 inches radius. It was made by Troughton, 136 Fleet Street, London. *c.*1796.

ALMANACS AND TABLES

This was a quiescent period for both almanacs and tables. The *Nautical Almanac* was redesigned in 1834 in a form more suitable for astronomers than for navigators; other almanacs followed the same trend. Two outstanding events that should have stimulated the publication of nautical tables were the discovery of the position line by Captain T. H. Sumner in 1837 and the introduction of the intercept method by Marcq St. Hilaire in 1875. A few tables of fundamental importance were, however, published towards the end of the period.

80. THE NAUTICAL ALMANAC for 1834; London, 1831.
81. BURDWOOD (JOHN): *Tables of the Sun's True Bearings or Azimuths*; London, 1858 and subsequently.
82. THOMSON (WILLIAM): *On the determination of a ship's place from observations of altitude;* London, 1871.
83. MARTELLI *Tables of Logarithms;* New Orleans, 1873. These tables are still popular today and have just been republished in the 1948 edition.
84. MARCQ ST. HILAIRE (A. BLOND DE): *Calcul du Point observe;* Paris, 1875. This is generally recognised as the first of the "short" tabular methods.

COMPASSES

The earliest compasses are believed to have consisted of slabs of lodestone floating on wooden floats in bowls of water. This form gave place to a needle thrust through a reed or piece of wood to form a cross, the reed acting as a float so that the element floated on the surface of the water. The type was probably well established by the end of the twelfth century. No contemporary illustrations or detailed descriptions exist from this period, though there are in existence sketches of 1269 which indicate the general idea.

About 1250 the pivoted type of dry compass, in which the needle was balanced on a pin point, appeared. The card is believed to have been added about 50 years later. Again we are almost completely in the dark as to what the compass looked like. The earliest pictures appeared about 1550 and then we only see the form of card and the needle. It is not until nearly 1600 that any definite picture appears. From about this date until about 1750 it is unlikely that the compass improved very much. The card was usually hand coloured and often had elaborate designs representing the planets, or pictures representing the four types of living creatures, animal, bird, reptile and fish. The needles were usually two pieces of wire formed into a parallelogram. The bowl was of wood hung in brass gimbals. About 1700 brass bowls instead of wood began to come into general use and they were adopted in the Royal Navy to the exclusion of wooden bowls, though the latter did not die out for a very long while.

Azimuth compasses have been used since the sixteenth century and some-

where about 1660 a very definite type came into use and lasted for 100 years, giving an entirely fictitious accuracy of minutes. In 1750 trials in the Royal Navy resulted in the introduction of Dr. Knight's compass into the Navy and the better found Merchant ships. This was the first attempt to produce a compass designed on really scientific lines.

Liquid compasses, i.e. compasses in which the bowl is filled with liquid and the card partially supported by a float to take the weight off the pivot, were introduced in 1813, but were not adopted for a long time because of difficulties with expansion, paint, etc. Though liquid compasses had been adopted by some Navies and ships they were not introduced into the Royal Navy until 1906.

In 1876 Thomson invented the light dry card compass which was for a while almost universally adopted and for a time proved a successful competitor to the liquid compass. It is still sometimes preferred.

The receptacle in which the compass is placed is called a binnacle (formerly *bittacle*, in a variety of spellings). At first this name was only applied to the receptacle for the steering compass, the azimuth compass being mounted on a "pillar". It was not until well on in the last century that the term was applied to the support for the azimuth compass.

For at least a century attempts have been made to find a compass which would transmit its readings at a distance, but success has only been attained within the last few years. Similarly, attempts had been made since about 1856 to find a compass which was unaffected by magnetism. In the early years of the present century the gyro-compass was introduced and in some of the larger ships this has now displaced magnetic compasses altogether.

85. Loadstone. Mounted in fretted and engraved brass. Suspension ring. Keep-plate connected by chain held by chased lions. These Loadstones were used for "retouching" compass needles and on the more important voyages were taken to sea for the purpose. 17th Century.

86. Mariner's compass with wooden bowl of the type in general use from the time of Columbus until the middle of the eighteenth century. The bottom is detachable so that the card can be extracted to enable the needles to be "retouched' (re-magnetized). The two needles are bent to form a diamond as will be seen in the accompanying photograph. The cardinal and half-cardinal points, other than North which is distinguished by a *fleur-de-lys*, are indicated by human figures representing the Sun, Moon, Jupiter, Mars, Mercury, Venus and Neptune. By William Farmer, near the Lime Kiln, Horsley Down. *c.*1750.

87. Mariner's compass with wooden bowl dating from the beginning of the nineteenth century. While compasses with wooden bowls were given up by the Royal Navy in 1708 and by the United States Navy in 1830 they continued in use in the less well found merchant ships till well on into the 19th century. While conforming in many particulars to the previous exhibit this one has an engraved card with a heavy flat needle $5\frac{1}{2}$ ins. long and $\frac{1}{2}$ in. wide. The card has been repaired with a piece of the Nautical Almanac for 1840 pasted on to the bottom. By G. W. Blunt, New York.

88. Azimuth compass used for finding the Sun's azimuth or amplitude and thence the variation of the compass. The compass was first "rectified" by turning the bowl until the cross threads under the glass were over the cardinal points of the card, that nearest to the sun being away from the pivot of the alidade. The alidade was turned until the shadow of the thread was thrown upon the slit of

the upright and the sun's bearing was then read off the from the scale. This is graduated every degree and by the diagonal scale readings can be read to 5 minutes of arc, an accuracy which was entirely absurd and fictitious as the observer was lucky if he aligned the bowl with the card within a degree. These compasses were introduced about the middle of the seventeenth century and lasted until late in the 18th. They are severely criticised by Joseph Harris in his *Treatise of Navigation*, 1730. Bowl by J. Fowler, London, probably about 1720. Card by H. Gregory, near the India House, London, probably about 1760.

89. Crown compass. Blanckley in his *Naval Expositor* 1750, said of hanging compasses that, "Flag Officers are generally furnished with them to hang up in their great Cabbins." The Danish makers in particular seem to have specialised in a form of hanging compass in which the metal frame took the form of a crown and for this reason such compasses came to be called crown compasses. Hanging compasses were supplied in the Royal Navy up to the middle of the 19th century. By Iver Jensen Borger, Kiobenhavn. *c.*1790.

90. Dr. Gowin Knight's steering compass. One of the difficulties experienced with early compasses was that the weak loadstones available were not able to induce magnetism in anything larger than soft wire needles such as those used in the exhibit. Dr. Gowin Knight showed how to make artificial magnets of great power and these enabled him to use heavy flat compass needles. His compasses were adopted for the Royal Navy in 1751 and, though his azimuth compasses were superseded by Walker's in 1795, it is probable that his steering compasses remained in use for many years longer. Knight's compasses were used by most of the great explorers of this period such as Wallis, Cook and Bligh. They were used in the better found merchant vessels as well as in the Navy. Invented by Dr. Gowin Knight. Made by George Adams, Fleet Street, London. *c.*1766.

91. Walker's meridional compass. Ralph Walker, of Jamaica, hoped to be able to use an accurate determination of the variation to give him the longitude. His Meridional Compass consists of a sun compass mounted on a magnetic compass thus enabling the error of the latter to be easily obtained. This method of finding the longitude was found to be of no value but the compass was so good that it was adopted for the Royal Navy from 1795 to 1819 as the standard pattern of azimuth compass. Owing to its cost it was usually only issued to ships going abroad whose masters could produce a certificate that they understood its use. Though purchase of these compasses was stopped in 1819 a number survived as late as 1850. By Ralph Walker. *c.*1793.

92. Admiralty standard compass of 1842. In 1837 the state of the Navy's compasses was so bad that a committee was appointed to study the whole question. One of the results of their deliberations was the design of a new standard compass which appeared in 1842 and was so much an improvement on those available that they were extensively adopted abroad. These compasses cost £25 a piece and in consequence the Admiralty refused to replace more than a small proportion of compasses at this time. The compass is shown mounted on a pillar binnacle of the type used about 1880.

93. Lord Kelvin's compass and binnacle. Sir William Thomson, afterwards Lord Kelvin, invented this compass and binnacle in 1876. It was adopted by the Royal Navy in 1889 to replace the Admiralty standard compass (exhibit 92) and was used until it, in turn, gave way to the liquid compass in 1906. It is still used in some merchant vessels. The chief points of interest are the very light paper compass card with its eight small needles and the arrangement of the

binnacle to accommodate magnets and spheres for the correction of errors caused by the steel of which the ship is built. By James White, Glasgow, 1876.

94. CROW'S AZIMUTH COMPASS. This is the first liquid compass, i.e. one in which the bowl is filled with liquid to damp the movement of the card, and a float is attached to the card to reduce the weight and consequently the friction on the pivot. In this case the float has positive buoyancy and floats up against a pivot below the glass. A raw hide disc in the bottom allows for expansion of the liquid. This compass, in most of its features, anticipated by nearly 100 years the modern liquid compass and only failed because of an insufficiently advanced manufacturing technique. It is believed that this actual compass was used by Captain Ross during his voyage of arctic exploration in H.M.S. *Isabella* in 1818. By Francis Crow, Faversham. *c.*1813.

95. ADMIRALTY PATTERN 195A LIQUID COMPASS AND BINNACLE. It soon became apparent that Lord Kelvin's compass was unsuitable for war vessels and in 1906 the Royal Navy adopted liquid compasses. These have gradually evolved into the modern compass seen here. Chief points of interest are the liquid filled bowl and the small diameter card to reduce the effect of swirl in the liquid. The azimuth circle with a single large prism so designed to avoid ill-aiming error i.e. it is possible to get an accurate bearing even if the circle is not trained exactly on the object. The binnacle has provision for the usual magnets, sphere and a Flinders bar for purposes of correction and in addition has a broad band containing coils for the electro-magnetic correction of the effects of degaussing.

96. JENNING'S INSULATED COMPASS. Many attempts have been made to insulate the compass from the magnetism of the ship without shielding it from the magnetism of the earth. The problem is of course impossible of solution. One of the first of these attempts was made by Jennings who constructed a compass with a double bowl, the space between being filled with iron filings. This compass was tried and found wanting in H.M.S. *Isabella* during Ross' Arctic voyage of 1818. Nearly thirty years afterwards Jennings was asking for an award from the Admiralty for his invention. By H. C. Jennings, 1818.

97. KATER'S STEERING COMPASS. This compass has the lozenge shaped needle advocated as the best shape by Captain Kater, Royal Engineers. Originally the weight of the card was partially taken off the pivot by threads but these have disappeared. The compass was used by Lieut. W. E. Parry in *H.M.S. Hecla* during the Arctic expedition in 1819-20. By Capt. Kater, 1819.

98. BARLOW'S CORRECTING PLATE. The first proposals for correcting a compass for the effects of the magnetic attraction of a ship's ironwork came from Captain Matthew Flinders, in 1805, but were not adopted. Next came Prof. Peter Barlow of the Royal Military Academy at Woolwich who invented the plate shown here. Too great claims were made for the value of this plate and when, it was found that in some ships it made matters worse instead of better, it fell into disrepute. Some were however still in use in 1850. By Peter Barlow. Compass by Gilbert, London, 1820.

99. MARINER'S RECORDING COMPASS. The compass card is covered by thin paper divided into 24 hours: it is raised and lowered every 3 minutes by clockwork. A small travelling steel pin pricks the paper when the card is in the "up" position, thus providing a record of the ship's course. Fitted in S.S. *Great Western* in 1848, the first ship to cross the Atlantic under steam the whole way, (in 1838). By David Napier, *c.*1848.

100. ADMIRALTY TRANSMITTING MAGNETIC COMPASS, TYPE 2. While this compass

conforms in dimensions and general design to exhibit 95 it is so arranged that an electric motor drives the bowl round so that it remains in line with the card. At the same time repeaters are operated electrically so that the ship's head, by the magnetic compass, can be read at distant parts of the ship. Two repeaters are shown, one giving an enlarged scale for ease in steering, the other with a more conventional circular card. The Total Error Corrector, here mounted above the repeaters, enables the repeaters to be put out of step with the compass by the amount of the Variation and Deviation so that they read True instead of Magnetic. By Admiralty Compass Observatory, 1946.

101. ARCTIC SLEDGE COMPASS. These small pocket compasses were made for use by sledging parties in the Arctic and were used in most of the expeditions between 1870 and 1912. They are covered with leather to prevent the metal freezing to the skin. *c.* 1875.

102. PHOTOGRAPHS OF UNDER SIDE OF COMPASS CARDS. This frame show typical arrangements of compass needles at various periods. (A) Lozenge shaped needles in general use in 17th and first half of 18th centuries. (B) Single flat needle of Dr. Knight's compass. Type in general use from about 1750 to 1850. (C) Four flat needles set on edge. The card of the Admiralty Standard Compass of 1842. (D) Eight light needles. Sir William Thomson's card of 1876. (E) Two needles and float. Liquid compass card. Admiralty Patt. 0195A compass of 1942 evolved from the chetwynd liquid compass of 1906.

103. CARVED BINNACLE FROM SHAMROCK II. Specially made for Sir Thomas Lipton's *Shamrock II* for the Atlantic crossing. The binnacle with its Erse inscription 'God Save Ireland' was removed when the yacht was racing.

104. MK. III PRISMATIC COMPASS. A liquid prismatic compass designed for Army use and used extensively where a good pocket prismatic compass is required ashore. It is also sometimes used in yachts.

105. TWO LIQUID COMPASSES WITH RING MAGNETS. These are examples of a modern development in compass design in which the compass needle is replaced by a single ring magnet inside the float. The ring magnet is magnetised across the diameter, a proceeding which, though attempted in the past, has only recently been perfected. The use of the ring magnet reduces swirl in the liquid, as compared with the ordinary arrangements of needles external to the float. It increases the distance between the magnet system and the soft iron correctors while retaining that equality of moments of inertia about all axes which has long been recognised as an essential feature of compass design.

These two examples, the Kelvin Hughes Centrex Compass and the Sestrel Compass, are accompanied by a specimen of a mounted compass card by Henry Browne & Son Ltd., employing the "circum" single ring magnet. In this case the magnet is made of the alloy known as Alcomax II, which can give a higher field strength than that which can be obtained with tungsten steel.

106. SESTREL SPHERICAL TYPE COMPASS WITH INTERNAL GIMBALLING. This is an attempt to improve the support of the sensitive magnetic element which the makers claim to be the finest approach to the problem so far produced in this country. The compass has a top hemisphere of transparent perspex and a hemispherical brass bottom. Within the sphere is a very light gimbal ring. This just clears the sphere and is so made as to turn over inside the compass with complete freedom. The ring supports the compass card, and, being suspended in a sphere of liquid, the weight of the card and magnet system in liquid has been reduced to an absolute minimum.

107. SESTREL "THAMES" PROJECTOR BINNACLE AND COMPASS. Specially designed to overcome the difficulty of correcting a magnetic compass in a steel wheelhouse, this equipment overcomes the difficulty caused by lack of space. If desired a gyro-compass can be mounted in front of the helmsman and the "Thames" Projector unit immediately above. Azimuth bearings can be taken at night without interference with the projection in the wheelhouse. The image of the standard compass card is projected by an optical system on to a mirror situated immediately below the binnacle and inside the wheelhouse. The optical unit is housed in a two-section brass tube which can be withdrawn from the binnacle at will without affecting the compass.

108. SESTREL LIFE BOAT BINNACLE AND COMPASS. This is the latest pattern of a life boat compass and conforms to the Ministry of Transport regulations. During the war, the life boats of all British ships had to carry compasses similar to this type with a luminous card.

109. SESTREL MOTOR CAR COMPASS. A dashboard liquid compass with vertical card for motor cars, sailplanes or gliders. A small corrector box is fitted beneath the compass to enable the user to correct deviation caused by the proximity of steel.

110. KELVIN HUGHES CENTREX COMPASS. This is an example of a compass in which use is made of the modern trend to replace the compass needle by a single ring magnet inside the float. The ring magnet is magnetised across a diameter a proceeding which, though attempted in the past, has only recently been perfected. The use of the ring magnet reduces swirl in the liquid, as compared with the ordinary arrangements of needles external to the float. It increases the distance between the magnet system and the soft iron correctors while retaining that equality of moments of inertia about all axes which has long been recognised as an essential feature of compass design.

111. HOLMES SUBMARINE COMPASS MODEL. The model shows how in a submarine the image of the compass card is projected down from the conning tower position into the hull of the boat when submerged.

112. KELVITE VERTICAL FORCE INSTRUMENT. This instrument is designed for comparing the vertical force on board ship with the vertical force on shore, to enable the Vertical Compensating Magnets of the Compass which is to be adjusted, to be placed in the proper position to correct the heeling error.

113. KELVITE DEFLECTOR. This instrument provides a means of adjusting compasses when no bearings of any kind are available, and is thus useful in dull or thick weather. It is designed on the principle that there is no error in the compass when the directive force of the needles is the same with the ship's head on any four points. By means of the deflector the directive force is measured with the ship's head on any four points at right angles to each other, usually the cardinals. The directive force on these points is read successively and duly noted. The usual correctors are then applied so as to render the directive force equal on all headings.

The advantages of a compass which would be independent of magnetism were recognised in the 19th century but it was not until 1906 that Anschutz had any success with the gyro-compass and not until 1908 that it was ready for sea trials. Sperry followed in 1911 and Brown in 1917.

114. THE BROWN TYPE 'A' GYRO-COMPASS is shown operating two repeaters, but more can be added if required. This Compass also operates in conjunction with

the "Brown" Automatic Helmsman. Attention is drawn to the hydraulic support for the sensitive Element which is provided by a column of oil kept at a mean level by a reciprocating pump. The Element follows the strokes of the pump in a vertical plane and by this means friction on the vertical axis is reduced to practically zero. The large scale readings of the steering repeater is also a notable feature.

115. THE SPERRY (MARK E.I.) MINOR GYRO-COMPASS, 1947, is the latest of a long line of Sperry Gyro-Compasses. This unit provides a small self-contained instrument which can be fitted in the wheelhouse, instead of operating repeaters from a position below. There are two dials: a large scale one for steering, and a small scale dial so that the officer of the watch can see the ship's course.

ALMANACS AND TABLES

The special requirements of the navigator were at last recognised by the separate issue of the first part of the almanac in 1896, followed by the publication in 1914 of the distinct abridged edition; similar almanacs were produced by other maritime countries. Before the first world war, the outstanding tables were those by Ball—the first to tabulate altitude directly—and Aquino's many contributions to navigation. The impetus of the war gave rise to many new tables—using both short and direct tabular methods; only a few can be shown. In this period the introduction of wireless time signals finally ended the use of lunar distances for the determination of longitude.

120. THE NAUTICAL ALMANAC (first part) for 1896; London, 1983.

121. BALL (FREDERICK): *Altitude Tables or Position Line Tables;* London, 1907. The first tables giving a direct tabulation of the altitude with the three arguments latitude, declination and hour angle.

122. AQUINO (RADLER DE): *Sea and Air Navigation Tables for solving all problems by inspection;* Annapolis, 1909. The first edition of one of Aquino's many books of tables.

123. THE NAUTICAL ALMANAC, ABRIDGED FOR THE USE OF SEAMEN, for 1914; London 1912.

124. DEUTSCHE SEEWARTE : *Hohen und Azimut der Gestirn deren Abweichung zwischen 30°S. und 30°N. liegt, fur 50° Breite;* Berlin, 1916. One of the earliest (if not the earliest) tables of computed altitude and azimuth, and certainly the most comprehensive for particular latitudes.

125. DAVIS (PERCY L. H.): *Alt.-Azimuth Tables;* London, 1918. These well known tables, extended to higher declinations and latitudes, are still in use.

126. BERTIN: *Tablette de Point Spherique sans logarithmes;* Paris, 1919.

127. SMART (W. M.): *The Sine Method;* London, 1919. The tables by Smart and Shearme appeared later in Inman's tables.

128. OGURA (SINKITI): "*New Altitude and Azimuth Tables*"*;* Tokyo, 1920. One of the best known "short" methods.

130. HALF CIRCLE. Brass lacquered frame, 6 inches radius; with a silver arc cut to 180° for use with back horizon. A prism is fitted in place of the usual horizon glass. Vernier, fitted with tangent screw, reading to 10 seconds. By C. Luttig, Berlin, *c.*1898, and sold by Hughes & Son, Fenchurch Street, London.

131. NIGHT OCTANT. Brass lacquered frame, 8½ inches radius, with an ivory arc cut to 125°. Vernier, fitted with tangent screw, reading to 30 seconds. This instrument was designed for taking stellar observations and is fitted with an

"elongating glass", a cylindrical lens which transforms the reflected star into a long luminous narrow line parallel to the horizon.

Invented by A. Laurent, Captain in the French Mail Steam Service, 1868, who stated "... with the use of the night octant ... I run my ship, by night, at full speed among shoals and reefs of the West India Sea without the least anxiety". By Dubas, Nantes, Breveté. Presented to the National Maritime Museum by H.M. Queen Mary.

132. TRAVERSE BOARD. These were used by Scandinavian, Dutch and probably German seamen up to the latter part of the 19th Century. The 32 points of the compass each have 8 equidistant holes to enable the course to be recorded every half hour of the watch by inserting a peg in the appropriate hole. Similarly the speed was recorded on the rectangular table every half hour; the first half hour of each hour of the watch on the left and second half hour on the right hand scale. This board was found on the Island of Barra in 1844.

SPEED AND DISTANCE RECORDING

The first estimation of a vessel's speed was by means of a chip of wood (hence the name *log*) thrown over forward and its passage timed at the poop. Later a line was fastened to a triangular piece of wood called the log ship. The line was allowed to run freely from a reel; a sandglass was timed at a mark on the line and when the glass had run out the line was checked and the speed estimated from the amount of line that had run out.

133. LOG-GLASS. This is a 28-second glass and was the usual type of glass which went with the common log-ship for speeds up to 6 knots. Over 6 knots a 14-second log-glass was used. The log line used with this glass was marked by knots every 47¼ feet.

Richard Norward, a seaman and reader in mathematics first recommended marking the log-line with knots. This was in 1637 and they were spaced every 51 feet for use with a half-minute glass. Log-glasses were used in the Navy till 1839. This particular glass is from the barque "*Almora*" of Greenock and was used between the years 1895 and 1898. The "sand" is probably powdered marble. Dated 1780.

134. BURT'S NIPPER. This was used to hold the log line clear of the vessel and to stop the line when the time was called out by the officer holding the sandglass. Dated 1830.

135. LAMB'S PATENT LOG. This log is in the form of a fish; the water flows through its mouth and turns the vertical rotator. Date 1830.

136. MASSEY'S TOWING LOG. About 1840, this was probably the first log made with any claim to great accuracy.

137. WALKER'S A.I. HARPOON LOG. First made in 1865 and still used by ships navigating where ice is liable to form on the log line.

138. WALKER'S ORIGINAL CHERUB LOG. This type of log is much used at sea today, The first manufacture was in 1894.

139. MASSEY'S CURRENT METER is used for measuring the flow of tides and currents.

140. STAR LOG by J. Bliss & Co., New York.

141. WALKER'S CHERUB III LOG, as used by the Merchant Navy to-day.

142. WALKER'S TRIDENT ELECTRIC LOG AND REPEATER. The Register is wired to a repeater which enables the readings to be made directly in the chart room.

143. WALKER'S SPEED VARIATION INDICATOR. This is designed to indicate changes of speed of a vessel through the water.

144. THE IMPROVED CHERNIKEEFF LOG. The principle of this log is to record linear velocity of the flow by measurement of the angular velocity communicated by the flow to a screw impeller. The impeller is loadless in that it transforms the energy of the flow into rotative motions without any appreciable loss by friction. It therefore has no slip or variable error. The impeller makes and breaks a pair of light contact springs; these are made at intervals corresponding to 1/400 nautical mile and as each contact occurs an impulse is transmitted to the Distance Recorder. Speed is read from a Speed Indicator actuated through a relay from the Distance Recorder.

145. PITOMETER LOG, TYPE M.M. Another type of submerged log. Based on hydraulic principles, it is operated by a Pitot tube and has no moving parts external to the ship. The speed of the ship through the water is measured and the speed and distance recorded on the dials.

146. A MODERN MARINE CHRONOMETER by Thomas Mercer.

147. DRAWING INSTRUMENTS. A box of mathematical drawing instruments contained in a black shark-skin case. According to an accompanying note, this box was given by Louis XVI to Euler, the celebrated Swiss mathematician and writer on Marine matters. By Canivet, à la Sphere à Paris, 1764.

148. STATION POINTERS. Made of brass, with silver circle. Vernier reading to one minute. Engraved with ducal coronet and name "Alfred". Formerly the property of Admiral of the Fleet, H.R.H. the Duke of Edinburgh (1844-1900). By Elliott Bros., Strand, London. *c.*1860. Presented to the National Maritime Museum by H.M. Queen Mary.

149. PARALLEL RULER. Made of ebony, and 18 inches long, these parallel rulers formerly belonged to H.R.H. Prince George Frederick Ernest Albert, later King George V. By H. R. Kempe, 1891. Presented to the National Maritime Museum, by H.M. Queen Mary.

ADMIRALTY CHARTS AND HYDROGRAPHIC SURVEYS

Admiralty Charts are compiled from hydrographic surveys which nowadays are executed by a great variety of authorities. The principal maritime powers each maintain a constant programme of surveying within their territorial waters. The R.N. Surveying Service is responsible for surveying home waters and those of many colonies and, as circumstances permit, other areas outside foreign territorial limits.

The Dominions of Australia, Canada, South Africa and certain of the Colonies now maintain hydrographic surveys of their own, whose work is gradually replacing the earlier surveys done by the Royal Navy. Harbour and River Surveys are in many cases carried out by local authorities e.g. Port of London Authority, Mersey Harbour Board, Southampton Harbour Board etc.

In the past famous navigators and hydrographic surveyors of many nations have contributed to the common fund of hydrographic knowledge. By far the greatest contribution over the last 150 years has, however, been made by the surveying service of the Royal Navy. Outstanding names since Cook are, Fitzroy who spent some 5 years surveying the east and west coasts of South America, W. F. Owen who surveyed about 30,000 miles of African coastline and Flinders and P. P. King, who surveyed extensively in Australian waters. But there were scores of others hardly less famous, such as Franklin, Kellett,

Beaufort, Moresby, Owen Stanley, Nares etc., whose surveys are to this day the only authorities for charts of a great part of the navigable globe.

Developments in surveying techniques and apparatus kept pace with the inventions of the steam and petrol engines and of electrical machinery and with the progress in related sciences. Some of the most striking changes have occurred however since the first World War, particularly in the field of sonic sounding, air survey, position fixing by radio and in tidal analysis and prediction.

The exhibits are not sufficient to show details of these developments but they give an idea of the effects on the published chart and of the changes in presentation.

154. THE DOWNS. Admiralty Chart No. 99 (early edition) first published 1808 from surveys in 1795 and 1819.

155. THE DOWNS. Admiralty Chart No. 1828 (current edition), first published 1932. This edition has been completed from surveys to 1945.

156. FARNE ISLAND TO BERWICK. Admiralty Chart No. 111 (early edition), first published 1835 from a survey in 1831.

157. FARNE ISLAND TO BERWICK. The current edition of Admiralty Chart No.111 first published in 1935 from surveys in 1929-30.

158. FARNE ISLAND. Fair Sheet from surveys in 1929-30 by Lt. Cdr. Fryer, R.N. in H.M.S. *Fitzroy*. Exhibit 158 was mainly compiled from this survey.

159. ENGLISH CHANNEL. By Halley. *c.* 1700.

160. ENGLISH CHANNEL &c. Admiralty Chart No. 1598 (current edition) first published in 1936 from Admiralty surveys and Foreign Government charts to 1936.

161. NORTH FORELAND TO THE NORE. Admiralty Chart No. L.1607 (Decca). First published in 1946 showing Decca hyperbolic lattice lines.

162. LOCATION OF THE AMPHIDROMIC, or no-tide point in the southern North Sea in 1840. By Captain W. Hewett, R.N., H.M.S. *Fairy*.

163. TIDAL INVESTIGATIONS. Specimens of the original tidal observations for 9-28 June 1835, taken by all countries in Europe. From these, the existence of an amphidromic point was deduced by the Rev. Dr. Whewell, and verified by Captain Hewett.

164. SAILING DIRECTIONS AND PLANS OF HARBOURS prepared by H.M. Ships about the middle of the eighteenth century, before the Hydrographic Department came into existence.

ALMANACS AND TABLES

This period has been one of the development of techniques rather than of principles. In the presentation of astronomical data there has been a greater appreciation of the specialised need of the navigator leading to cdepartures from the older forms; the G.H.A. method has, however, not yet been adopted by all countries. It is under consideration in the Abridged Nautical Almanac. A few typical almanacs are shown.

170. THE NAUTICAL ALMANAC, ABRIDGED FOR THE USE OF SEAMEN, for 1948; London, 1947.

This shows little change for the first issue for 1914, other than the introduction of E and R in 1929 largely as a consequence of the change of origin of astronomical time in 1925.

171. The american nautical almanac, for 1949. Tabulates both R.A. and G.H.A.

172. The american nautical almanac, for 1950 (Specimen copy). A complete new G.H.A. almanac.

173. Ephemerides nautiques, 1948. Largely taken from the *Connaissance des Temps.*

174. The Japanese nautical almanac, for 1948. Uses E for all bodies, with one page to each day.

175. Almanaque nautico para 1948 (Brazilian). An example of a straightforward G.H.A. almanac.

Similarly the emphasis in the corresponding tables has been towards improvement of technique, and the simplification of the arithmetic, without, however, any really new principle. Graphical methods of presentation were also introduced.

176. Dreisenstok (J. Y.): *Navigation Tables for Mariners and Aviators,* H.O.208; Washington, 1928.

177. Ageton (A. A.): *Dead Reckoning Altitude and Azimuth Tables,* H.O.211; Washington, 1931. The two tables above are representative "short" methods, each with their adherents.

178. H. O. publication no. 214: *Tables of Computed Altitude and Azimuth;* Washington, 1937. This magnificent collection of nine volumes is the most comprehensive set of altitude-azimuth tables in existence.

179. Comrie (L. J.): *Hughes' Tables for Sea and Air Navigation;* London, 1938. Probably the best presented "short" method.

180. Burton (S. M.): *Nautical Tables;* London. A modern set of nautical tables.

181. Garcia (Juan): *Tables de lineas de Posicion de Altura;* Madrid, 1944. Introducing the involute method of drawing position lines.

182. Deutsche seewarte, *Azimut diagramme fur alle Breiten, Deklinationen und Stundenwinkel;* Hamburg, 1944. A direct diagrammatic presentation of azimuth.

185. Star globe. The identification of stars is generally carried out either with a Star Globe or by special Tables or by graphical methods. This Star Globe is mounted on a polar axis inside a meridian circle. The meridian circle is adjustable for latitude while the globe revolves on the polar axis for adjustment to the local sidereal time. Auxilliary vertical circles under the horizon circle allow altitude and azimuth to be read off. The results are an approximation from which the stars can be identified. By Henry Hughes Ltd., 1899.

186. Willis navigating machine. This machine invented about 1930 by Edward J. Willis, an American, can be used for quickly performing the trigonometrical calculations which arise in connection with navigation at sea, or in the air. It has also been used for the calculation of the paths of meteors, or shooting stars. The machine exhibited is of the heavier type used for marine navigation. The aviation type is a third of the weight.

There are five protractors designed to read accurately by means of verniers the five angles of navigation and astronomy, viz: declination, latitude, hour-angle, altitude and azimuth. These five graduated arcs are coupled together in such a way that the five readings are self-consistent, so that if the declination, latitude and hour-angle are known and set on the machine the corresponding altitude and azimuth can be read off.

The five protractors are on five axes which all intersect in a single point representing the observer's position, marked O in the accompanying diagrammatic representation of the machine. The Altitude-Azimuth turret represents

a theodolite set up at this point. The Hour-angle axis which passes through the centre of the Hour-angle circle, represents the axis of the heavens, which passes through the pole star. The observed celestial body (e.g. the Sun) is at the point A on the declination arc. The declination arc, when revolved about the hour-angle axis, carries the body along its celestial path and the altitude and azimuth of the body are recorded on the respective altitude and azimuth circles just as if the theodolite had been set up and actually pointed at the body (the Sun) itself.

187. MODEL OF NO. 90 LIGHT VESSEL. Lent by the Elder Brethren of Trinity House.

188. WOOLLARD PRACTICAL RULE OF THE ROAD BUOYAGE SYSTEM INSTRUCTOR. This apparatus is for teaching practical applications of the 'Rule of the Road at Sea', and of the buoyage system. Different combinations of lights can be switched on to represent ships on different bearings. Miniature navigational buoys are fitted on the revolving platform, and imitations of ship's sirens and fog horns have been incorporated.

CHARTWORK INSTRUMENTS

On the chart the navigator fixes his position in relation to known positions—the land, geographical co-ordinates etc. The primary instruments he uses are dividers and parallel rulers, with which he lays off his course to steer from a position derived from land bearings, astronomical observations or estimation.

189. 24" CAPTAIN FIELD'S PARALLEL RULE. A type of Rule still commonly in use at sea today. 1701.

190. ROLLER RULE. Parallel lines, from the compass rose for a course, or from the land to lay off a bearing, are transferred by rolling the rule across the chart. 1903.

191. STATION POINTERS. These are used for plotting horizontal angular bearings of three objects. The method is used where greater accuracy than can be obtained with compass bearings is needed, or where bearings are obscured from the compass position. 1890.

MODERN MARINE SEXTANTS

The most notable improvements in the design of sextants since 1760 have been the micrometer screw reading and the artificial horizon. The former is now in universal use to replace the Vernier. The bubble horizon, originally designed for air use can be fitted as an attachment to the normal sextant or is used in special bubble sextants.

192. 'NE PLUS ULTRA' SEXTANT.A modern marine sextant. The arc is divided to 130° and reads to 12 seconds. By Heath & Co. 1947.

193. V. E. SEXTANT. A marine sextant made of light alloy. The arc is divided from minus 5° to 120°. By Henry Hughes Ltd. 1945.

194. MARINE SUPER SEXTANT (integrating bubble type). A sextant for use when the natural horizon is obscured; a horizontally reflected ray from a bubble in a spherical level provides an artificial horizon. By Henry Hughes Ltd. 1945.

195. DOUBLE SEXTANT. This instrument is used in hydrographic surveying when a double angle is required. The arcs are divided from zero to 150°. By Henry Hughes Ltd. 1946.

196. GERMAN KREISELSEXTANT. Taken from the first U-boat to surrender at the end of the second World War. The instrument uses a gyro-stabilised horizon, the gyro being driven by compressed air which is driven in with a pump. In 1886 Admiral Fleuriais of the French Navy produced a gyro sextant also driven by compressed air.

SOUNDING AND DEPTH RECORDING

200. LEAD AND LINE. The earliest form of sounding the depth, that of 'heaving the lead', is still in use to-day. The line is marked at different lengths (in fathoms) and the lead has a piece of tallow in the bottom so that the nature of the sea bed can be seen from the sand or shingle that sticks to it.

201. KELVIN ELECTRIC SOUNDING MACHINE. This method of sounding was originally invented by the late Lord Kelvin in 1875. A chemically coated tube sealed at one end is lowered on a cable by means of the sounding machine to the sea bed. The pressure of water relative to the air pressure in the tube forces the water into the tube and discolours the coating. The discolouring is measured against a special rule from which the depth of water can be read off.

202. DOBBIE McINNES DEPTHOMETER. When the instrument is lowered the depth of water trapped in it is a measure of the vertical distance it has been lowered.

203. ECHO SOUNDING. Echo sounding was first introduced in about 1925 in the form of an oscillator or hammer which transmitted sound waves of 1000 cycles from the ship to the sea bottom where they were reflected back to a microphone in the ship. The time of travel was measured by a revolving switch and on a suitable scale the depth could be indicated. Later, supersonic means were introduced by means of the crystal and, finally, the magneto-striction oscillator was designed by the British Admiralty.

With the magneto-striction oscillator a frequency of 15-30,000 cycles is used and provides a means of obtaining greater energy for deep water or narrow beam for shallow water.

In the Admiralty Echo Sounder electrical vibrations are reflected through the steel plate of the ship to the bottom of the sea and back where they are picked up by an oscillator which reconverts them into electrical energy.The electrical impulse is passed through an amplifier to the moving pen of a Recorder system and marks each signal on starch-iodide paper. This provides a continuous record of the sea bottom from 3" of water to 5,000 fathoms.

204. BOAT GEAR ECHO SOUNDER. A self-contained recording instrument produced in 1931 and one of the first using the magneto-striction oscillator. Its design was the result of an Admiralty development contract to produce a transportable high-speed machine suitable for hydrographic surveying.

205. A 1947 NAVIGATIONAL ECHO SOUNDER. MS 21 B Echo Sounder.

206. MARCONI 'SEAGRAPH' ECHOMETER. Another modern echo sounding equipment.

207. ECHO CHARTS. Some examples of recordings produced by the Hughes Recording Echo Sounder.

MARINE RADIO

RADIO COMMUNICATION. By the end of the 19th century ships started the fitting of wireless telegraph apparatus which, although not directly a navigational aid, was of very great help to the mariner. Through this equipment the navigator was able to get weather reports, information of navigational dangers and accurate time signals with which his chronometer could be checked and rated;

these facilities, when he was perhaps thousands of miles from land, provided hitherto unobtainable information which was of the greatest value. In addition, if his vessel should be in distress, he had a means not only of calling for assistance but of being able to state his position so that help could reach him quickly.

209. EARLY TYPE OF MARCONI TRANSMITTER. An early shipborne telegraph transmitter was in use at sea as early as 1897. It has a 10" Induction Coil to produce the spark by means of which early wireless transmission was effected.

210. TWO EARLY MARCONI RECEIVERS. The first, a Coherer receiver in use in 1897, uses a glass tube containing two electrodes between which metal filings "cohered" on receipt of a signal. The second receiver consists of a magnetic detector and multiple tuner of the type in general use during the first decade of the 20th century.

211. MODERN MARCONI TRANSMITTER. A modern "Oceanspan" transmitter for sending either speech or morse code. This transmitter, which is installed in some of the newest ocean liners, covers all the general marine communication frequencies and is provided with "clock-stop" setting to pre-selected frequencies.

212. TWO MODERN SHIPBORNE RECEIVERS. Both receivers are designed to the latest G.P.O. specifications. The *Mercury* affords medium and long wave reception, while the *Electra* is for short and medium waves.

DIRECTION FINDING

Soon after radio had provided the mariner with a means of long distance communication, it was realised that it could also directly assist him in determining his position, and direction finders were developed to determine the direction from which a radio transmission was coming. The navigator used them to determine the bearings of shore transmitters and so to fix his position at the intersection of two bearings.

There has since grown up a very widely used service with chains of small radio transmitters, known as D.F. beacons, set up around the major seaboards of the world, and most ships today carry direction finders. The service has been supplemented in some areas by larger and more accurate direction finders on shore which take bearings of a ship's transmitter and pass the information to the ship by radio telegraph or telephone.

Also in this category come certain special radio beacons which employ a rotating beam transmitting a coded time signal. This allows the bearings to be determined on board ship with an ordinary wireless receiver and a stopwatch. Again in the direction finding category comes a new system first used by the Germans in the last war under the name of *Sonne* and now employed in this country under the name of *Consol*. In this system the shore station radiates a series of swinging dot-dash coded beams; the bearing is determined by counting the number of dots and dashes heard on an ordinary shipborne receiver and comparing it with code numbered bearing lines on a special chart. The *Consol* system is equally useful at sea and in the air, and it requires no special equipment in the ship. It is far more accurate than normal D.F.

213. EARLY MARCONI DIRECTION FINDER.

214. MODERN MARCONI DIRECTION FINDER. This is one of the latest types available for shipborne use. It consists of a self contained receiver unit fed from a compact shielded loop aerial.

215. CONSOL RECEIVER. This is an ordinary ship's receiver tuned in to the *Consol* station at Bush Mills in Ireland. On this receiver the characteristic coding of dots and dashes can be heard and the count can be compared with the chart which has the Bush Mills *Consol* bearings overprinted on it. (Note: a model of a *Consol* transmitting station is shown in the Air Section).

HYPERBOLIC POSITION FIXING SYSTEMS

During the last war a number of new systems, known as "hyperbolic position fixing systems" were developed. In the *Loran* system two shore stations each transmit a pulse of radio energy and a receiver in the ship is used to compare the times at which the two pulses are received. For any given time interval between the arrival of the two pulses there is a particular difference in distance of the ship from the two stations and this locates the ship on one particular line of constant range difference; the line has a shape known to mathematicians as the hyperbola. A similar measurement from another pair of stations locates the vessel on a second hyperbola and the intersection of the two fixes the ship's position. Special charts are available, overprinted with sets of curves for the various *Loran* stations throughout the world. *Loran* is intended as a long range ocean aid (up to about 700 miles by day and about 1,300 miles by night) and is of an order of accuracy of about 5 to 10 miles at 600 miles, deteriorating to about 20 miles at maximum range. In *Loran*, as in all the systems in this category, the measurement is essentially in terms of *distance* (based on a measurement of time and the accurately known speed of travel of radio waves) and this can be determined with greater accuracy than the *direction* of receipt of a radio signal.

Another of the many systems of this type is the *Decca* system. Basically similar to *Loran*, it employs a completely different technique, the shore station radiating continuous waves instead of pulses. The phases of the waves from each of three stations gear fixed relations to each other; a receiver in the ship detects these waves, compares their phases and indicates the result automatically on dial instruments, the pointers of which rotate as the ship changes position. To fix the position of the ship the navigator reads the dials and finds correspondingly numbered hyperbolae on the special *Decca* charts. This system is a medium range system (approximately 500 miles) of very high accuracy (about 50 feet to ½ mile depending on which part of the coverage area the vessel is in).

216. SHIPBORNE LORAN RECEIVER. The receiver includes a special circuit by means of which "markers" can be placed on the two received pulses as seen on a cathode ray tube. The time differences are then shown directly on a drum-type counter. The receiver also includes built in test equipment by means of which the accuracy of the timing circuit can be checked.

217. SHIPBORNE DECCA RECEIVER. The receiver exhibited is picking up the British *Decca* chain and the readings on the dials can be compared with the large scale chart showing the *Decca* lattice for the London region. In early forms of *Decca* there was some ambiguity as the *Decca* numbers are repeated in different regions (or "lanes") and it was necessary to know one's *approximate* position by other means before the *accurate* information of *Decca* could be used; in this latest model a system of "lane identification" is incorporated and this can be seen working. (see also 389).

However precisely a navigator may know his position, he cannot proceed in bad visibility unless he knows the positions of other ships and of navigational dangers in his immediate vicinity. It is here that navigational radar is of inestimable value.

In radar of the type here considered the transmitter sends out a train of short pulses of radio energy from a rotating aerial and some of this energy is reflected from any object which it strikes. The reflected energy is picked up by the same aerial and passing through the receiver is displayed as a point of light in its correct position on the screen of a Plan Position Indicator (P.P.I.). As the aerial rotates a complete plan picture is built up showing the actual position of every object above water and the shape of the nearby coastline. Operating in dark or fog and having a range (in modern shipborne equipments) of up to some 20 or 30 miles, it provides the navigator at all times with a collision warning device and, when near land, is an instrument by which he can see his own position at a glance. Marine Navigational Radars are now beginning to find their way into many merchant ships. The various makes on the market differ in layout and points of detail, rather than in principle or performance.

A simple adaptation of shipborne radar is being used on shore for the operation of Ferries. Where it would be uneconomical to fit each of a number of ferry vessels on a short run with its own radar, it is often possible to instal one set on shore where its P.P.I. shows the whole stretch of water and to pass information to the ferries themselves by radio telephone.

Special radars of similar principles, but usually of far more elaborate construction, can also be of assistance in the running of a large modern port. A radar of high performance installed in a well chosen position can provide a detailed picture of every ship in the approaches to the port whatever the visibility. Docking officials are kept informed of the movements of vessels and information can be conveyed by radio telephone to the pilot of a vessel which does not carry its own radar or when some part of the channel is beyond its radar range or "out of sight round the next bend". In this way the equipment is of some use even in clear weather and may help to keep the port open in fog or other bad visibility.

218. E.M.I. SHIPBORNE NAVIGATION RADAR. The installation has two main units, a binnacle to be mounted in the wheelhouse containing the P.P.I. and some of the control equipment and an aerial unit for mounting in the ship's superstructure. Associated with the aerial is the transmitter and part of the receiver.

219. MARCONI SHIPBORNE NAVIGATION RADAR. The installation has three units, the main display console, transmitter and receiver; and an aerial unit which can be mounted either on the ship's superstructure or on a mast.

220. KELVIN-HUGHES NAVIGATIONAL RADAR. There are two main units, a binnacle for mounting in the wheelhouse containing the indicator and some of the control equipment and an aerial unit for mounting on the ship's superstructure which has associated with it the transmitter and part of the receiver.

221. COSSOR NAVIGATIONAL RADAR. This equipment consists of three major units, an indicator unit for the bridge or wheelhouse, an aerial which can be mounted on the mast or superstructure, and a third unit which can be mounted anywhere within about 50 or 60 ft. of the aerial and contains the transmitter, receiver, modulator, and some ancilliary equipment which runs unattended.

222. RADAR AT WALLASEY FERRY. This exhibit is a model of the display Console used in the radar installed for assistaing the operation of the Wallasey Ferries across the river Mersey. The model shows the P.P.I. screen of this Console and projected on to this screen is a film taken of the actual P.P.I. screen at Wallasey; the movements of the ferries and of other vessels in the river can be seen. The model of the Console also shows parts of the radio telephone equipment used by the control officer to talk to the masters of the ferry boats.

223. HARBOUR SUPERVISION RADAR, LIVERPOOL. This exhibit is a model of the Harbour Supervision Radar erected in 1948 at Liverpool for supervising the approaches to the port. Specially designed for harbour use, the equipment is the first of its kind in the world. The model shows the 80 ft. ferroconcrete tower atop which is mounted a large 15 ft. rotating aerial and the building nearby which houses a special display Console, transmitter and receiver, power generating equipment and a communication room.

The photograph is of the display Console which contains six new type P.P.I.'s, one for the whole of Liverpool Bay and the rest for parts of the approach channels. The other photographs are of typical P.P.I. displays.

The equipment is used to pass information to the various Harbour Authorities and, by radio telephone, to the pilots of vessels in the channels. The equipment which has been in use since August this year is already helping pilots to handle their ships in winter fogs.

224. MODEL OF A BRITISH THOMAS HOUSTON SHIPBORNE NAVIGATION RADAR. This set is in prefabrication construction and it would therefore be impracticable to exhibit it except in this form.

AIR NAVIGATION

MAPS AND CHARTS. Maps form the primary means of navigation in any medium, and the first air maps were topographical ordnance survey maps of a scale appropriate to the speed of flight and the wide field of view of the pilot. However certain features on the ground stand out and are more easily recognised from the air than others. Such features are frequently not the ones shown most prominently on an ordnance survey map. Although this was realised from the very early days of flying it took many years before the need for special air maps became generally accepted. During the last decade more attention has been given to the design of maps suitable for air navigation and this has culminated in the series of charts sponsored by the International Civil Aviation Organisation which are being designed by member countries specifically for air use.

When the ground is obscured by fog or cloud and when flying over the sea it is not possible to navigate by map-reading. The air navigator then proceeds by dead-reckoning; by calculating and plotting his position on a chart. In the past the term 'chart' has generally been used for maps specially used for plotting, but the word has now been adopted by I.C.A.O. to apply to all air maps. Following marine practice, plotting charts are generally on Mercator's projection. Topographical features are kept to a minimum to avoid obscuring the navigator's pencil lines. Modern charts are printed in colour, instead of black, for the same reason.

240. AIR MAP, 1911. This map was specially drawn and used for the first Aerial Post service of the United Kingdom, which was inaugurated in September, 1911 by a flight between Hendon and Windsor. It is notable that the map is almost entirely confined to features easily recognised from the air; towns, railways and rivers.

241. AIR MAP FOLDER, 1916. Scale: 1" to 30 miles. These maps cover the Sleaford area, Midlands, and Eastern Counties. Sketches of landmarks are included on the coastline.

242. TOPOGRAPHICAL MAP. Scale: 1" to 10 miles. This series was in general use up to the outbreak of the Second World War. The confusion of detail betrays the fact that it was not originally designed for air use.

243. ROUTE MAP, CRANWELL TO ISMAILIA. Scale: 1/1,000,000. A number of topographical maps have been joined together to form a route map for use by the Royal Air Force formation which broke the Long Distance Record on a flight to Australia in November, 1938.

244. R.A.F. TOPOGRAPHICAL SERIES, Scale: ¼" to 1 mile. Basically an Ordnance Survey map, this is overprinted with a military grid used by Fighter Command.

245. R.A.F. TOPOGRAPHICAL SERIES. Scale: 1/500,000 (1" to 8 miles). These maps were used during the Second World War and are still one of the best air maps. Features recognisable from the air are prominent and most other details are eliminated.

246. U.S.A. AERONAUTICAL CHART. Scale 1/1,000,000 (1" to 16 miles). This is typical of air charts at present used in U.S.A. Radio and Aeronautical facilities are overprinted prominently.

247. I.C.A.O. AERONAUTICAL CHART, 1948. Scale 1/500,000 (1/ to 8 miles).

248. MERCATOR PLOTTING CHART, 1918.

249. MERCATOR PLOTTING CHART. Scale 1/1,000,000 at 56°N. (1" to 16 miles). This is a standard plotting chart used by the R.A.F. during the Second World War.

250. JAPANESE MERCATOR CHART. This chart, captured during the Second World War, was designed both for plotting and for map-reading.

251. GERMAN MERCATOR CHART, 1943. Topographical features are included on a chart primarily intended for plotting.

252. I.C.A.O. AERONAUTICAL PLOTTING CHART, 1948.

253. POLAR CHART ON STEREOGRAPHICAL PROJECTION. Scale 1/4,000,000 (1" to 63 miles). This chart is overprinted with Grid Lines, used for measuring direction with reference to the Greenwich Meridian, instead of local meridians, owing to the rapid convergence of the latter in polar regions.

ALTIMETERS

To measure height, the standard aircraft altimeter uses the principle that atmospheric pressure decreases with height above sea level. It is a sensitive aneroid barometer with the scale calibrated in units of height. Since the actual relaion between pressure and height varies, and does not necessarily conform to that on which the altimeter is calibrated, correction has to be made for such variation to obtain true height. Computors have been designed for correcting the altimeter.

The standard altimeter measures height above sea level, or some other datum chosen by setting the zero reference, and hence it does not necessarily

indicate height above the ground over which the aircraft is flying. This is an important disadvantage, from the standpoint of aircraft safety, when the ground is not visible. During the Second World War radio altimeters were developed, which indicate height above the ground. These are sometimes called Terrain Clearance Indicators.

254. EARLY ALTIMETERS. This instrument, by Negretti and Zambra, was designed for use at the Central Flying School.

255. ALTIMETER, WATCH TYPE MK. I.

256, ALTIMETER MK. VB. This altimeter is representative of the types used by the Royal Flying Corps during the First World War.

257. ALTIMETER, EARLY R.A.F. PATTERN. This instrument has an adjustable zero datum. It allows for alterations of pressure on the ground. If the altimeter is set to zero before take-off, it will register height above the aerodrome. If set to height of the aerodrome it will register height above sea level.

258. MODERN SENSITIVE ALTIMETER. Range 0-35,000 feet. On this instrument allowance is made for variation of surface pressure by providing a barometric scale. When the pressure at a particular place is set on the scale the pointers of the instrument are automatically adjusted to read the height above that place. The three pointers indicate 100's, 1,000's and 10,000's of feet. The instrument mechanism is compensated for changes of temperature and it is designed to be unaffected by change of position or by acceleration.

259. SEMI-SENSITIVE ALTIMETER. Range 0-65,000 feet. This instrument is designed for high altitude aircraft and was used in an automatic observer as a standard for determining the altitude during the recent world height record flight. A specially designed mechanism, which is fully compensated over a wide temperature range operates two pointers which indicate altitude in 1,000's and 10,000's of feet.

260. SENSITIVE AIRCRAFT BAROMETER. Range 1,050-150 millibars. The aircraft barometer indicates the absolute pressure in millibars by means of two concentrically mounted pointers. The pointers indicate 10's and 100's of millibars respectively. In conjunction with a radio altimeter this instrument can be used to measure the pressure gradient along an aircraft's flight path. Except in equatorial regions, this pressure gradient can be used to calculate the component of the wind acting on the aircraft's beam. The instrument may also be used for vertically separating aircraft which are holding over a point near an aerodrome.

AIR SPEED INDICATORS

Air Speed Indicators are designed to indicate the speed of an aircraft relative to the air. The most usual method of airspeed measurement is by means of a differential pressure guage which measures the difference between the dynamic pressure due to the aircraft's forward speed relative to the air and the static ambient pressure. Normal air speed indicators are calibrated for air at standard conditions, i.e. 15°C and 1013.2 millibars and consequently a correction has to be applied for conditions appertaining during flight to obtain true air speed.

261. ELEMENTARY AIR SPEED INDICATOR. A pressure cup mounted in the airstream is deflected by the air resistance against a spring and its deflection records the airspeed on a scale visible from the aeroplane cockpit.

262. PRESSURE HEAD FOR AIR SPEED INDICATOR. This insturment is used in conjunction with the air speed indicator to record the speed in relation to the air, and

is connected to it by means of flexible tubing. It is usually mounted in an exposed position at the front of the aeroplane, as clear as possible from the propeller slip stream and the wing surface. The instrument consist of two tubes, known as the "static" and "pitot" tubes respectively. The static tube is closed at the end and has small holes at the sides communicating with the air. Pressure inside this tube is not affected by its passage through the air. The pitot tube is open at the end and is arranged to face up stream. It records the atmospheric pressure plus the additional pressure produced by the speed of flight and the wind. The pressure difference between the two tubes is proportional to the density of the air and the square of the velocity of the machine.

263. EARLY AIR SPEED INDICATOR. This Elliot instrument uses a liquid manometer to measure the pressure differential between pitot and static heads. It is calibrated directly in units of air speed.

264. OGILVIE AIR SPEED INDICATOR. This instrument was made at the aerodrome of the Royal Aero Club at Eastchurch early 1913. Tubes from the pitot and static tubes are introduced to the case on different sides of a flexible diaphragm. Increase of pitot pressure causes deflection of the diaphragm against a spring and this deflection is transferred by a lever system to the pointer, registering airspeed on a fixed scale.

265. LOW RANGE AIR SPEED INDICATOR. Range 10-150 mph. Modern air speed indicators use a flexible capsule in place of a diaphragm. Pitot pressure is introduced to the capsule, contained in a sealed case connected to the static head. Deflection of the capsule is transmitted to the pointer by means of a level system.

266. STANDARD AIR SPEED INDICATOR. Range 40-350 knots. The instrument is designed for use on aircraft in the medium speed range category. It employs a simple, robust mechanism which magnifies the movement of a sensitive capsule, to indicate air speed in knots. The mechanism is fully temperature compensated. The pointer makes $1\frac{3}{4}$ revolutions for its complete range.

267. KOLLSMAN TRUE AIR SPEED INDICATOR. Range 100-500 mph. The Kollsman True A.S.I. indicates true airspeed over its specified range at altitudes from 0-35,000 ft. above sea level and temperatures from —30° to +50°C. The instrument consists of an airspeed unit, similar to a conventional air speed mechanism, the magnification of which is modified by an altitude unit and temperature unit. The altitude unit prime mover is an evacuated capsule, while the temperature unit comprises a capsule operated from a bulb fitted outside the aircraft.

268. AIR MILEAGE UNIT. The Air Mileage Unit is designed to provide an output shaft whose average speed is proportional to true air speed. It is for use either with an electro magnetic counter to record air miles flown, or with an Air Position Indicator to compute air position. The unit makes use of a null method in which the pitot pressure is balanced against a pressure generated by a small electrically driven fan. The output shaft is driven by gears from the fan motor.

269. MACHMETER. Range 0.5 to 1.0 Mach. The Machmeter is designed to indicate the Mach number, which is the ratio of the true velocity of an aircraft to the local speed of sound. This is an important requirement in very high speed aircraft due to the aerodynamic effects near sonic speeds. The instrument gives a direct Mach number indication at all altitudes up to 50,000 ft. despite the fact that the speed of sound decreases with increase of altitude. To achieve this end the mechanism consists of an airspeed unit whose magnification is varied by means of an altitude capsule.

270. Appleyard air speed computor. This is an early computor designed to correct for the effect of varying density on the reading of an air speed indicator.

271. Height and air speed computor mk. i. An instrument designed to effect rapid mechanical computation of true height and true air speed from the readings of the altimeter and air speed indicator.

272. True air speed computor (u.s.a.)

273. True height computor (u.s.a.)

274. Dalton computor—appleyard scale. The computor has a circular slide rule for rapid solution of speed, time and distance problems. In addition two small scales are provided for correction of altimeter and air speed indicator readings.

AIR COMPASSES

Early aircraft compasess were of the type used in small boats, but they were not dependable when subjected to vibration and accelerations experienced in aircraft. The effect of vibration was reduced by cushion mounting, liquid damping and improved pivot design. The effect of acceleration could not be removed so simply. Acceleration of an aircraft, especially in turns, throws the plane of rotation of the compass needle off the horizontal, and the vertical components of the earth's magnetic field then causes errors in reading. Since the errors are greatest on turns through magnetic north and south, they have given rise to the terms 'northerly turning error' and 'southerly turning error'. Although improvements in compass designs have reduced their effect, acceleration errors are inherent in compasses operating entirely on magnetic principles.

The presence of ferrous metals and electrical circuits in the region of the cockpit is an additional source of errors in air compasses. Although these errors may largely be compensated by means of corrector magnets, the deviation of the compass are liable to change over a period of time and they vary with magnetic latitude. To avoid such errors remote indicating compasses have been developed so that the magnetic element may be mounted in a position on the aircraft relatively free from magnetic disturbance.

Acceleration errors are eliminated by combining in one instrument the north-seeking properties of a compass and the stability of a gyroscope. The most recent gyrostabilised remote indicating compasses use an induction element to sense the earth's magnetic field in place of a compass needle. The electrical transmission to the repeater indicators can be used to control the automatic pilot in order to maintain a correct course, and also to monitor automatic dead reckoning equipment such as the Air Position Indicator.

280. Commander creagh-osborne's compass 1909. In 1909 Commander Creagh-Osborne noticed that the card of the compass in Mr Cody's aeroplane started to revolve as soon as the engine was started. To remove the effects of vibration he laid a surveying compass in a bed of cotton waste in a wooden box and with this arrangement made a successful flight on 27 October 1909.

281. Patt. 200, the first standardised british air compass, 1913. This compass was designed as the result of a conference between Naval and Military air interests. The bowl rests on horsehair in an outer container in which it is prevented from turning by trunnions working in rubber-lined, U-shaped sockets. Otherwise the design of the compass follows naval practice. It will be noted

that the card is graduated from 0-360° a feature ever since adopted by aviators in preference to the then marine practice of graduating in quadrants from 0-90°. The bowl is made deep enough for the card to tilt 20° without fouling, a necessary feature with an ungimballed bowl.

282. PATT. 250 COMPASS, 1915. In 1915 it was discovered that the horsehair suspension was insufficient to prevent the card turning in certain aircraft. The vibration of the aircraft was in fact causing the pivot to vibrate and to spin the card like a juggler spinning a plate on a billiard cue. To overcome this the pivot was inverted so that the point was on the card and rested in a jewel cup instead of the opposite arrangement. Inverted pivots had several times been tried for marine compasses but never adopted. From this date they have been universally used for air compasses.

283. TYPE 5/17 VERTICAL CARD COMPASS, 1917. About 1916 it was discovered that when an aircraft altered course through North the tilting of the compass card due to acceleration caused it to be affected by the vertical component of the earth's magnetism and to show a smaller turn than that actually made and possibly even a turn in the opposite direction. This is called Northerly Turning Error. At this period the Admiralty Compass Observatory, who designed compasses for the R.N.A.S., favoured a short period compass as it settled quickly after a turn. The 5/17 compass was designed for this reason and between 1917 and 1919 between 50,000 and 60,000 were made. The magnet system is very light and there is no float.

284. ROYAL AIRCRAFT FACTORY, MK. II, 1915. The Royal Aircraft Factory, Farnborough, considered that the Northerly Turning Error was best defeated by having a long period compass whose needles would not easily be disturbed. The Mk. II compass was designed for the Royal Flying Corps with that end in view. In some of these compasses the card was offset on the needles so that the variation was corrected and the compass read true in France. The naive use of "deviation" for "variation" in the inscription on this exhibit will be noticed.

285. THE FIRST APERIODIC COMPASS, 1918. This compass was the result of experience in World War I. The light magnet system is fitted with wires which, acting as brakes in the liquid, make the compass practically dead beat if disturbed Another feature is the introduction of a steering grid. By means of a graduated scale the grid ring is set at the correct position for the course to be steered and the aircraft is then steered so that the bar on the magnetic element is kept parallel to the grid wires.

286. TYPE 01 COMPASS WITH CENTESIMAL SCALE, 1923. This compass has what is called a centesimal scale. The course of the aircarft is obtained by taking the figure on one of the four whiskers and appending to it the two figures which it indicates on the scale.

287. TYPE 02 OBSERVER'S COMPASS, 1924. This compass though designed as long ago as 1924 is still installed in flying boats. It is fitted with an azimuth circle for taking bearings and this is arranged so that bearings can be observed at considerable angles of dip.

288. TYPE P.11 PILOTS COMPASS, 1943. This is a smaller, improved version of the P.4 compass which was introduced in 1926. These Pilots' steering compasses are fitted for grid steering as in exhibit 6. The parallel grid lines have been replaced by a T formation which prevents flying the reciprocal course accidentally. The tubes on the grid and magnetic element are filled with luminous compound.

289. E.1. COMPASS, 1947. This is a small emergency compass designed for use in the event of a failure of the main remote indicating type of compass. It is designed to be read to the nearest ten degrees only and to take up as little space as possible. Correctors for both horizontal and vertical magnetism are fitted.

290. PIONEER MAGNESYN COMPASS (U.S.A.). This instrument is a combination of a liquid-filled pivoted needle compass and an inductor system for transmission. The needle seeks north and the magnetic field of the needle, acting upon the inductor system of the compass sets up voltages therein which are used to operate distant repeaters.

291. GYRO FLUXGATE COMPASS (U.S.A.). This is an earth inductor compass consisting of three "fluxgate" elements which are sensitive to a magnetic field, and which provide a suitable voltage for operating a follow-up and repeater system. The fluxgate elements are mounted on a vertical gyroscope so that they are always kept horizontal and are therefore influenced only by the horizontal components of the earth's magnetic field. A master indicator is used within which the follow up and transmission mechanism is situated, together with a cam and differential mechanism for the correction of deviation. Correction can also be made for magnetic variation. This compass is extensively used in large American aircraft.

292. THE R.A.F. DISTANT READING COMPASS. This instrument is an example of a gyromagnetic compass in which a directional gyroscope is used as the datum. A follow up system enables distant repeaters (in this case of the step by step type) to be operated. A pivoted needle magnetic compass in conjunction with suitable electrical circuits "monitors" the gyroscope so that, should the latter drift, it is compelled to realign itself with the mean position of the magnetic needle. The gyroscope provides the necessary stability during turns and accelerated flight.

293. AN AIRSHIP COMPASS MADE FOR R.100. The design of this compass was based on naval types but damping filaments were fitted to the card as in air practice. The aluminium binnacle is fitted with correcting magnets and with chain boxes for correcting quadrantal deviation. It will be noted that the latter were fore and aft, indicating that R.100 must have been expected to have a negative Coefficient D. In ships Coefficient D is invariably positive.

294. TYPLE 06 HAND BEARING COMPASS. This is a small azimuth compass conveniently fitted to a handle. Originally designed for use in Kite Balloons during World War I it was later adopted for small aircraft. At the present day it is a most convenient instrument for small wooden yachts. Its danger is that it is sometimes used by the ignorant in positions where only a corrected compass will give accurate results.

295. PLATH COMPASS (SECTIONED)—HORIZONTAL SCALE. Manufactured by C. Plath of Hamburg, this shows in cross-section the typical construction of a horizontal reading magnetic compass.

296. PLATH COMPASS (SECTIONED)—VERTICAL SCALE.

297. GYRO-MAGNETIC COMPASS MK. 3. The Gyro-Magnetic Compass Mark 3 (G.3) uses the output of magnetic detector elements, suitably amplified, to monitor an electrically driven directional gyro. The complete system consists of five units: a Detector Unit mounted in the aircraft wing-tip, a Master Indicator at the Navigator's station, a Directional Gyro and Compass Control Panel in the Pilot's cockpit, and a Phase Sensitive Amplifier. The system provides both pilot and navigator with accurate compass indications unaffected by turning,

acceleration, or gyro wander errors. An output is available at the Master Indicator to monitor an Auto-Pilot and to operate up to six step-by-step repeaters. The total weight of the system, less cable, harness and invertor is 25 lbs. The power supply required to operate it is 3 phase, 400 c/s 115v. 80w. and 27v. D.C. The model exhibited is mounted on a perspex display stand showing the position each unit would occupy in an aircraft. 1945.

298. SPERRY GYRO-MAGNETIC COMPASS, GYROSYN TYPE C.L.2. (MK.4.B.). This compass consists of an electrically driven Directional Gyro mounted on the instrument panel and monitored by a "Flux Valve" detector unit. This detector unit senses the direction of the lines of force of the earth's magnetic field and is normally mounted in the wing tip or tail plane of the aircraft where magnetic deviation is at a minimum. The type C.L.2. also incorporates a Navigator's Master Indicator with a large-size scale having a power repeater system for Automatic Pilots, Air Position Indicator, Radar etc.

THE ASTROCOMPASS

The Astrocompass is used to check course by reference to a celestial body such as the sun. It is used when change of deviation in the magnetic compass is suspected in flight. Knowing the aircraft's approximate longitude and the time it is possible to calculate the declination and local hour angle of the body using the Air Almanac. After levelling the instrument the approximate latitude and the declination and hour angle are set on the appropriate scales and the celestial body is then observed through a stile. The true course is indicated on a scale at the base of the instrument.

The Astrocompass may be used to identify an unknown star. It may also be used to take relative bearings of landmarks.

DIRECTION INDICATORS

300. DIRECTIONAL GYRO (PRE-WAR DESIGN)I A standard fitting on the flight instrument panel of all but the smallest aircraft. It provides a gyro-stabilised dead-beat azimuth reference and is of particular value in turns, when the magnetic compass cannot be relied on owing to turn errors. Has to be aligned at intervals with the magnetic compass in straight flight, due to slow drift of the gyro. The movement is contained in an airtight case which is connected to a vacuum pump and the gyro is spun by jets open to atmosphere.

ALTITUDE INDICATORS

A pilot maintains his aircraft in straight and level flight and controls it in turns by reference to the horizon. When the horizon is not visible, as on dark nights or in cloud, such a horizontal reference has to be produced artificially in the aircraft. Early altitude indicators depended on the principle of the liquid level, but the effects of acceleration produced large errors in their readings. The technique of flying by reference to instruments, "blind flying" as it is called, took a great step forward when the gyroscope principle was adopted in aircraft instruments.

305. GOUGH-TURNER INCLINOMETER. This type of instrument was used in the First World War and indicates whether the aircraft is laterally level. It is composed of a tube bent to the radius of a circle with a metal ball which, remaining at the lowest point of the arc, gives a direct reading of bank in degrees. To make the instrument "dead-beat" the ball is immersed in liquid and is provided with

two small balls (one either side) which act as dampers to the movement of the larger ball.

306. INCLINOMETER. ADMIRALTY TYPE. MARK AD II. This is a fore and aft level gauge of the First World War period. Red coloured liquid of sufficient quantity to half fill the interior is sealed in the tube and rests half way up the visible portion when the aircraft is flying level; when climbing, the liquid rises in the tube, and vice versa when descending.

307. GYRO TURN INDICATOR. This instrument, which is of German manufacture, was designed about the end of the First World War. It is a very early version of the modern electrically driven Gyro Horizon.

308. GYRO-HORIZON (PRE-WAR DESIGN). A standard blind flying instrument. Utilising a vertical gyro it provides an indication of the attitude of the aircraft in pitch and roll. The horizon bar is stabilised by the gyro and always remains horizontal while the instrument case carrying a miniature aeroplane moves with the aircraft. Pitch and Bank attitude are indicated in a natural sense by the position of the miniature aeroplane in relation to the gyro-stabilised horizon bar. On this early instrument the degree of bank is shown by the pointer moving about the scale on the top half of the instrument face. Instruments used today have a correct sense indication, the pointer moving about a scale on the bottom half of the instrument face. This instrument is driven by a vacuum supply in a similar manner to that iused with the Directional Gyro.

309. ELECTRO GYRO HORIZON TYPE H.L.3. An electrically-driven Gyro Horizon with greatly improved performance compared to the earlier air-driven instrument. Has freedom from topple and operates through 360° in roll and 80° in climb or dive. The movement has considerably increased gyroscopic inertia obtained by using a rotor running at 23,000 r.p.m. Fully tropicalized and driven by 115 volt, 3 phase, 400 cycle A.C.

RATE OF TURN AND SIDE-SLIP INDICATORS

310. OGILVIE AERO TURN INDICATOR (FIRST WORLD WAR). This indicator is used in conjunction with two tubes mounted as far apart on the aeroplane as possible (usually on the outer wing struts) and arranged to receive the free flow of the relative wind. Connection from these tubes is made to either side of a diaphragm from which suitable mechanism is arranged to rotate the pointer. Any deviation in a horizontal plane from straight flight causes a difference of pressure in the tubes due to the rotational acceleration and deceleration of the extremities of the wings, this difference causing deformation of the diaphragm and showing by the movement of the pointer in which direction rotation is taking place.

311. STATIC HEADS MK. I. These were used in conjunction with the Ogilvie Aero Turn Indicator. The heads were designed for use on a D.H.9A machine.

312. TURN AND SLIP INDICATOR MK. 2. This is a modern instrument designed for use on light aircraft. It is driven from a venturi or suction pump. The precessional force exerted by a horizontal axis gyroscope, constrained to turn with the aircraft, drives a pointer indicating the rate of turn. The side-slip indicator works on the simple pendulum principle, and consist of a curved glass tube containing an agate ball, the movement of which is suitable damped. This type of slip indicator is generally favoured by American pilots. 1947.

313. TURN AND SLIP INDICATOR MK. 10. Working on similar principles to the Mk. 2 instrument this indicator registers turn and slip by means of pointers, the

presentation favoured by most British pilots. The instrument is electrically driven from an aircraft's 24v D.C. supply. 1945.

RATE OF CLIMB INDICATORS

Rate of Climb Indicators are more correctly termed Vertical Speed Indicators, since they measure the vertical component of the aircraft's speed in climb or descent. They are normally operated by a mechanism which measures rate of change of atmospheric pressure. This is achieved by measuring the pressure differential between two vessels, one of which is open to the ambient pressure by connection to a static head, the other being sealed from ambient pressure except for a small orifice. When height is changing, the change of pressure in the second vessel lags behind that in the first, and the difference of pressure in the two vessels provides a measure of vertical speed. In modern instruments the two vessels consist of a flexible capsule mounted inside a sealed case. A metering unit restricts the flow of air into and out of the case when height is changing and this causes the capsule to deflect. Deflection of the capsule drives the pointer, indicating vertical speed.

315. BUBBLE STATOSCOPE. This is a very early instrument constructed by the British Wright Co., Ltd. The differential pressure between the ends of a bent glass tube is recorded by the motion of a liquid bubble, originally contained in the tube, to either side of its central position. This provided an indication that the aircraft was ascending or descending. The instrument was probably designed for use in balloons or airships.

316. HIGH RANGE RATE OF CLIMB INDICATOR. Range: 0-10,000 feet/min. Climb and Dive. This modern instrument has been designed to fill the requirement for an instrument capable of measuring the extremely high rates of ascent and descent of jet propelled aircraft. The design of the instrument is such that it is capable of withstanding overload pressure up to 22,000′/min. rate of ascent and 40,000′/min. descent without impairing its accuracy. Indication is by means of a single pointer with zero at "9 o'clock".

317. LOGARITHMIC RATE OF CLIMB INDICATOR. Range: 0-4,000′/min. climb and dive. The instrument is designed for use on aircraft with normal rate of climb and employs a conventional capsule and metering unit type of mechanism. The scale is logarithmic giving greatest sensitivity at the lower end of the scale where it is most required for let downs and approaches to landing in conditions of nil or poor visibility.

DRIFT SIGHTS

When navigating an aircraft along a chosen route, allowance has to be made for the fact that the aircraft is carried by the wind in the same manner as a ship is borne by the tide. Except when the wind is blowing from ahead or astern it carries the aircraft off its course. The effect is called drift, and the drift is defined as the angle between the course flown by the aircraft through the air and its track over the ground. Drift sights enable the air navigator to measure the drift by observing the motion of the ground below the aircraft. Early drift sights were fitted with parallel horizontal grid wires. which could be rotated in azimuth until objects on the ground, viewed from above the sight, appeared to travel down the wires. The drift angle was then indicated on a scale. Ground speed could be measured approximately by timing the

passage of objects between beads mounted on the wires and performing a calculation involving the height of the aircraft. Later developments took the form of optical sights, with suitable magnification, and a rotatable graticule in place of the grid wires. Periscopic drift sights enable the navigator to view objects astern of the aircraft in order to obtain drifts by back bearings. One of the difficulties experienced in using drift sights is that the instability of the aircraft in flight causes lateral motion of the grid wires or graticule with respect to objects observed on the ground. This difficulty is eliminated in such instruments as the American Pioneer B3 Drift Meter in which the graticule is stabilised in the horizontal plane by means of a gyroscope.

318. COURSE SETTING BOMB SIGHT MK. I. This instrument was designed during the First World War by Major H. E. Wimperis. It can be used for drift finding or for determining the wind by observing drifts on two or more courses.

319. WIND GAUGE BEARING PLATE. This also was designed by Major Wimperis. It enables drift to be measured by tail bearings and wind velocity to be obtained by the "wind-star" method, i.e. by obtaining drifts on two or more headings.

320. AERO BEARING PLATE. This is an example of the simplest form of aero bearing plate designed to measure the angle of drift, or track made good, by the observation of objects beneath the aircraft. It is of German manufacture and of a type used during the First World War.

321. COOKE AIRSHIP SIGHT. This sight was used for taking drift and ground speed observations from airships. The optical system is pendulous to avoid levelling before use. A graticule is aligned with the motion of objects on the ground viewed through the sight. A pair of cross wires on the graticule are used for timing the passage of objects to determine ground speed. The effective spacing of the cross-wires can be varied accordingly to the height of the airship, and the sight is used in conjunction with a special stop watch which reads ground speed directly.

322. TAIL DRIFT SIGHTS. This periscopic sight was designed by Mr. L. B. Booth of the Royal Aircraft Establishment in 1929. It can be used to obtain drifts by means of back bearings and also to determine ground speed.

323. PERISCOPIC DRIFT SIGHT. This German instrument is similar to Tail Drift Sight.

324. FLOOR TYPE DRIFT SIGHT. An R.A.F. instrument designed for use by the pilot of a single-seater aircraft. The grid wires can be rotated by a remote control. It is fitted with a large concave lens to provide a wide field of view from the pilot's position. Subsidiary scales are included to enable wind velocity to be observed by flying courses parallel with, and at right angles to, the wind. 1918.

325. DRIFT RECORDER MK. II. Designed by Mr. Lamplough of R.A.E., this sight is fitted in the side of an aircraft's fuselage. In additon to the usual rotatable graticule, including ground speed lines, it has a recording system by means of which the path followed by objects on the ground across the field of view may be recorded on a frosted glass plate. A number of recordings are taken and the drift may be deduced by judging the mean direction of the traces. This system is used to obtain accurate drifts in spite of lateral motions of the aircraft.

326. PERISCOPIC DRIFT SIGHT MK. XX. This was developed from the optical system of the Drift Recorder Mk. II to meet the special needs of the de Havilland Dove aircraft. The sight is periscopic, in that the observer sees an image of the ground, but the field of view is fixed, its centre being a point abeam and 15° from the vertical. The recording system is not included and drifts are obtained by means of a rotatable graticule in the usual manner. 1946.

327. B3 DRIFT METER (U.S.A.). Although designed primarily for the measurement of drift, this instrument may also be used to find ground speed and to measure relative bearings of objects on the ground. The sight permits very accurate vertical drift measurement by virtue of its gyro stabilised graticule.

NAVIGATION COMPUTORS

Navigation computors are used to solve vector problems involving the air velocity, wind velocity and ground velocity of an aeroplane. They are generally fitted with a circular slide rule to solve problems involving time, speed and distance.

328. COURSE AND DISTANCE CALCULATOR (C.D.C.). This was designed and used during the First World War and for some years afterwards. It was invented by Rolls Appleyard and was based on the naval Battenberg Course and Distance Indicator. It will solve the triangle of velocities, but is difficult to use for more complex problems.

329. COURSE AND SPEED CALCULATOR (C.S.C.). Designed by Captain Bygrave in 1929 this reproduces the velocity triangle mechanically.

330. COMPUTOR (RUSSIAN)

331. COMPUTOR (JAPANESE)

332. COMPUTOR (FRENCH)

333. DALTON DEAD RECKONING COMPUTOR (R.A.F. Mk. III). The computor, designed by Philip Dalton in U.S.A. uses the graphical method of solving vector problems. It is particularly convenient for solving more complex problems such as interceptions, This is the standard computor used by the R.A.F.

AIR SEXTANTS

335. FLYING BOAT SEXTANT. The first sextant used in aircraft were of the marine type. This, however, is a recent model and was still provided in addition to a bubble sextant for use in R.A.F. flying boats during the last war. When using the marine sextant it was customary to fly very low over the sea, so that height could be estimated and a clear horizon obtained. Under conditions when it can be used this sextant provides a very accurate means of determining an aircraft's position. The sextant is $3\frac{1}{2}''$ radius and is fitted with a micrometer screw giving readings to 1 minute of arc. 1941.

336. BAKER SEXTANT. This instrument is designed for the purpose of measuring the altitude of heavenly bodies and avoiding the dip correction by the use of two horizons seen in two opposite directions. An "L" shaped telescope is provided with an object glass at its upper end, and the eyepiece contains two lenses on either side of a right-angle prism. Above the object glass is a plate, upon which are mounted two prisms whose functions are to collect light from a front and a back horizon. Above the horizon prisms, a third prism rotates about an axis perpendicular to the main axis of the telescope and reflects the image of the sun or star into the field of view. When the image of the heavenly body bisects the space between the two horizons in the field of view it has been "brought down" to the true horizontal and its altitude is read off the graduated scale.

337. R.A.E. SEXTANT Mk. V. This was one of the first and most famous of bubble sextants. It was invented by Mr. L. B. Booth of the R.A.E. in about 1920. This type of sextant eliminates the necessity of a visible horizon line, and can

therefore be used under all circumstances when a celestial body is visible. This is realised by a special optical design which causes the imagine of a bubble in a spherical level to move (when the sextant is unavoidably tilted by the rolling and pitching of the aircraft) in the same direction and at the same rate as the star. A graduated drum can be rotated until the star is "brought down" to the horizon, and its altitude and the sidereal time registered on a special table fitted to the instrument. Both the bubble in the spherical level and the graduated drum can be illuminated for night use, while two coloured glasses of different degrees of transparency are provided for solar observations.

338. R.A.E. SEXTANT Mk. VIII. A later design than the Mk. V, this sextant was also invented by Mr. L. B. Booth, and was used on many famous civil flights. It utilises the bubble horizon principle, but should the natural horizon be available it can be used in place of the bubble. The sextant is fitted with a median working drum, on which individual altitudes can be recorded. The mean of several readings can be chosen by setting the drum to the mid-value of the readings recorded. Rheostat illumination of the scale and bubble is provided by a self contained battery. 1930.

339. BUBBLE SEXTANT Mk. IX, This sextant was used by the R.A.F. at the outbreak of the Second World War. It is an averaging sextant by means of which six altitudes may be taken rapidly, their average being recorded automatically. It is built in two halves. The left half of the instrument carries the bubble and its collimating system, the clutch lever and its left handle, containing a dry battery and lighting switch attached to the upper part of the handle. The right half of the instrument contains the sextant proper, consisting of two mirrors, together with the gear for measuring their rotation (scaled in terms of altitude), the averaging mechanism and necessary lighting for the scales. The storage case for the sextant contains two spare bulbs, space for two dry batteries, and a plug adapter for use with either 12 volt or 24 volt circuits. 1942.

340. PIONEER OCTANT Mk. IV. An American sextant designed for use in Naval aircraft, this instrument can be used with either a bubble or a visible horizon. It uses a clockwork-driven graphical averaging device on which a scriber automatically produces a graph of altitude against time over a period of two minutes. The average altitude can be obtained by inspection of the graphs.

314. PIONEER OCTANT Mk. V. This sextant is fitted with an automatic averaging device driven by a clockwork motor. It was used by the United States Services during the Second World War.

342. FAIRCHILD SEXTANT TYPE A10. An American median marking bubble sextant. When the instrument is sighted manually readings of altitude are registered automatically at one second intervals on a marking disc, enabling an average reading to be selected upon completion of the "run". A counter indicates the altitude when the mark corresponding with an observation is indexed against the marker.

343. BUBBLE SEXTANT (JAPANESE). This sextant is an exact copy of the R.A.E. Bubble Sextant Mk. V.

344. GYRO SEXTANT SKS 42 (GERMAN). This sextant, made by C. Plath of Hamburg uses a gyroscope to define the horizontal. The gyro is set in motion by compressed air from a hand pump. The integrating machenism will run for one, two or three minutes. It is understood this sextant was originally developed for use in U boats. See also exhibit 196.

345. R.A.F. BUBBLE SEXTANT Mk. IX BM. The Mk. IX BM sextant is similar in construction to the Bubble Sextant Mk. IX from which it was developed. It has the additional refinement of an automatic averaging mechanism, driven by clockwork, which gives the average observation at the end of a run of one or two minutes. A magnifying system is included for use on stars of low magnitude or at dawn and dusk.

346. R.A.F. PLANISPHERE Mk. IA. The planisphere is used by an air navigator to facilitate identification, and to determine the approximate azimuth and altitudes of the star and planets used in air navigation.

347. R.A.F. ASTRODOME. The Astrodome is fitted in the top of the fuselage of an aircraft to provide the navigator with an observation post for taking celestial observations. It is constructed of perspex to very fine tolerances and is calibrated to provide corrections to sextant altitudes for refraction of light passing through the dome. The sextant is normally suspended from a hook at the top of the dome when observations are taken.

ASTRONOMICAL TABLES AND COMPUTORS

Just as the first sextants used in aircraft were marine sextants, so the nautical methods of calculating position from sextant altitudes were at first applied to air navigation. It soon became evident that these methods were too slow and cumbersome for air use. The need for more rapid solutions to suit the faster pace of air navigation was realised by the end of the First World War. Many different methods of "reducing" sextant altitudes have been invented and they fall into four general classes; tables, mechanical computors, graphical solutions, and star curves. Among the first computors was Captain Bygrave's logarithmic slide rule for solving spherical triangles. Captain Baker, who invented the Baker Sextant, also designed in 1919 a Navigation Machine, on which position line curves of the sun and certain stars were moved along over a map mounted on rollers. This was undoubtedly the forerunner of the star curves published by Commander Weems in the late twenties, and of the Astrograph used by R.A.F. navigators during the recent war.

The first air almanac seems to have been Japanese. One of the earliest designed for air navigation was the U.S. experimental edition of 1933, which introduced the tabulation of Greenwich Hour Angle, which most air almanacs now use.

Although there always have been, and still are, differences of opinion among air navigators in choice of method for "reducing" sextant altitudes, at the present day short tabular solutions seem to be most generally preferred.

350. THE AIR ALMANAC FOR 1933. (U.S.A.)

351. EPHEMERIDES AERONAUTIQUES for 1936 (French). The first regularly appearing almanac solely for air navigation; it was based on the tabulation of "versed ascension".

352. THE AIR ALMANAC (British) for 1937.

353. THE AIR ALMANAC (British) for 1939.

354. THE AIR ALMANAC (British) for 1948.

The three editions show the rapid development to the present form introduced in 1944.

355. THE AMERICAN AIR ALMANAC, for 1948.

356. EPHEMERIDES AERONAUTIQUES, for 1948.

These agree very closely and are the same in principle as the *Air Almanac;* the French almanac has been completely revised since 1946.

357. THE RUSSIAN "AIR ALMANAC" for 1947.

358. ALMANAC AERONAUTICO for 1947 (Argentine).
These are typical G.H.A. almanacs.

359. ABRIDGED NAUTICAL ALMANAC, for 1948. (Japan). The only air almanac to use E instead of G.H.A.; it is stated to have been published for air use from 1926.

360. ALTITUDE AND AZIMUTH ALMANAC, for 1948. (Japan). The most advanced almanac yet published, tabulating directly the altitude and azumith of the Sun, and thus combining an almanac and reduction tables.

361. WEEMS (P.V.H.): STAR ALTITUDE CURVES; San Diego, 1928.

362. ASTRONOMICAL NAVIGATION TABLES, London, 1939. The first special altitude-azimuth tables for use in the air.

363. MYERSCOUGH AND HAMILTON: RAPID NAVIGATION TABLES, London, 1939. Typical of the many "short" methods specially prepared for air use.

364. "EASY ASTRONOMICAL NAVIGATION TABLES". (Japanese).

365. TABLES DE HAUTEUR ET D'AZIMUT (French). These are typical of several sets of tables following the lines of the A.N.T. (No. 51).

366. HOHENTAFELN NACH STEFNZEIT (German).

367. STAR TABLES FOR AIR NAVIGATION, H.O.249. (U.S.A.).
The latter table is the apotheosis of all the many tables that have appeared in this form—of which the former (No. 365) is typical.

368. ASTRONOMISCHER RECHEN-ATLAS. (German). This is a graphical version of one of the "short" methods that have been so frequently tabulated.

369. BYGRAVE POSITION LINE SLIDE RULE. A navigational slide rule designed to calculate the altitude of a celestial object as it would be seen from a given point on the earth's surface at a given time. The theory involved is the resolution of a spherical triangle determined by the three points—the pole, the observer's position, and the sub-solar (or sub-stellar) points, sufficient elements of which are known to enable a unique solution to be obtained. By using the instrument, the necessary calculations can be performed in about two minutes with an accuracy to one minute of arc. By Henry Hughes Ltd., 1915.

370. ARG. I COMPUTER. Astronomische Rechengerat (A.R.G.I.). Made in Germany about 1943 for the use of the Luftwaffe. It is designed to solve the astronomical spherical triangle, giving altitude and azimuth when latitude, local hour angle and declination are known.

Operation
1. Set latitude to 90° by turning the knob until it clicks.
2. Set cross wires of central microscope to L.H.A. and Dec. of object.
3. Turn knob to bring latitude to wire in microscope (Breite).
4. In central microscope read position of crosswire to give altitude and azimuth.

371. THE ASTROGRAPH. At a given instant of time it is possible to conceive a series of lines on the earth's surface along which the altitude of a particular celestial body has the same value. Such lines could be drawn on a globe and actually take the form of a series of circles about the sub-stellar point (the point on the earth where the star is directly overhead). By observing the altitude of the body with a sextant at that instant, an observer would be able to decide on which one of those circles he was situated: they are in effect circles of position corresponding with sextant altitudes. For the same instant a similar family

of position circles could be constructed for a number of different stars and these would form a grid of intersecting position lines for that instant of time. With the passage of time the earth rotates about its axis from West to East and such a position line grid would remain unchanged in shape, but move over the earth from East to West. In the Astrograph, a grid of this type is drawn on a film, for a given band of latitude, based on two or three of the brightest stars visible at any period. This film is projected on to a chart covering the same band of latitudes and it can be moved along on rollers by the navigator to simulate the rotation of the earth. The navigator takes a sextant altitude of one of the stars represented on the grid and, having set the film to correspond with the time of his observation, he can draw a position line on his chart by interpolating between the altitude curves projected for that star. By repeating the process with another star he is able to obtain a "fix".

AUTOMATIC DEAD RECKONING EQUIPMENT

Instruments under this section are designed to eliminate the necessity for manual plotting in order to maintain a continuous record of the aircraft's position. The Air Position Indicator was fitted in a large proportion of R.A.F. aircraft during the last war and it is still widely used. Actually it is customary for the navigator to keep a manual check plot when using instruments of this type in case they should become unserviceable.

Being linked directly to the compass these instruments eliminate the errors which would be introduced by the pilot not always sustaining the precise course intended. Moreover they take account of every motion of the aircraft, in turns and when manoeuvring, which is not possible when keeping a manual plot. Being linked directly to a true air speed instrument, they eliminate the necessity of computing true airspeed at frequent intervals.

372. Air position indicator. An aeronautical navigational instrument working in conjunction with the Air Mileage Unit and any suitable transmitting compass to give the air position continuously. In short the instrument keeps a continuous air plot. The heading of the aircraft is obtained from the transmitter compass, and this is used to resolve continuously the true air speed (obtained from the T.A.S. motor of the Air Mileage Unit) into North-South and East-West components, which, after conversion, are fed to counters indicating degrees and minutes of latitude and longitude. 1943.

373. Ground position indicator. The use of this instrument in conjunction with the Air Position Indicator provides a means of maintaining an automatic and continuous ground plot of an aircraft's position. The air position is fed from the A.P.I. through electrical transmission to repeater motors inthe G.P.I. and the wind velocity is set manually. These two factors are combined to give the ground position by means of a reflected arrow projected on to the Navigator's chart. The instrument has a scale selecting device enabling it to be used in conjunction with either 1 : 250,000 or 1 : 10,000,000 scale map series. 1945.

This instrument was developed primarily for R.A.F. Bomber Command for use on the final approach to the target, when the navigator was preoccupied with the accurate determination of position by radar means and with ascertaining the wind strength for bombing purposes.

SPECIAL EXHIBITS

375. The Johnston memorial air navigation trophy. This trophy is a silver

plaque, 18" by 14", showing the World on Mercator's projection. It was prepared by the Guild of Air Pilots and Navigators of the British Empire as a memorial to Squadron Leader E. L. Johnston, who was killed when navigating the Airship R.101, which crashed at Beauvais, France, in 1930, on its maiden flight to India. The conditions of the award are:

1. The Prize is awarded by the Court of the Guild.
2. It is held by the recipient for one year.
3. To be awarded for the most outstanding feat or performance of aerial navigation, for the development of principles of air navigation, or for flights involving the development of the technology of navigation by a person, or persons, engaged in a civilian capacity. Navigation of a routine or spectacular character is not the essence of the award.
4. The flights to be considered are those made prior to the 30th June and subsequent to the last period reviewed for award.
6. In the case of Aircrews, the Captain or Navigating Officer will have physical possession of the prize during the period of retention.

The previous holders of the trophy are:—

1931. F. C. Chichester for his flight from New Zealand to Sydney via Norfolk Island and Lord Howe Island.
1932. H. Hinkler for his South Atlantic flight from Natal (Brazil) to Bathurst (Gambia).
1933. J. A. Mollison for his trans-Atlantic flight from Portmarnock (Dublin) to New York.
1934. Not awarded.
1935. E. W. Percival for his flight to Algiers and back in 14 hours 30 minutes.
1936. Jean Batten for her flight from Lympne to Port Natal including South Atlantic crossing, 10th November 1935.
1937. A. S. Wilcockson for his three successful return flights from Foynes to Botwood, Newfoundland. Miles: 1,990. Empire Flying Boat, *Caledonia*.
1938. D. C. T. Bennett for his flight of the Mayo composite aircraft from England to Egypt.

376. THE HUGHES NAVIGATION STAND. The stand has been designed to display some of Hughes Aircraft Instrument in a similar position to that in which they would appear in a large aircraft. At the top is the Periscopic Bubble Sextant which can be manipulated and withdrawn from its mounting as in practice. Below this is mounted the Ground Position Indicator which projects the position of the aircraft downwards on to a chart. The rear panel includes the standard navigational instruments such as Air Speed Indicator, Altimeter, clock., etc., and in the centre is mounted an Air Position Indicator. The Air Mileage Unit, which is connected to the Air Position Indicator, is housed below the panel portion. To the right-hand of the panel is a Periscopic Drift Sight which operates from a device simulating the passage of the ground below the aircraft.

377. THE FIRST LONG DISTANCE FLIGHT ON WHICH COMPLETE RELIANCE WAS PLACED ON ASTRONOMICAL NAVIGATION BY A PILOT FLYING ALONE. At 6.45 a.m. on 28th March, 1931, Francis Chichester took off from Auckland, New Zealand in a wooden Moth aeroplane, fitted with floats, to fly across the Tasman Sea to Sydney, Australia. He chose a route via two small islands at which he was to land and refuel, the total distance being 1,720 miles. During each stage of the flight observations of the sun were taken by the pilot with a marine type box sextant (shown) while actually flying the aircraft.

Chichester set himself the problem of making a landfall at Norfolk Island, barely seven miles in area, after flying a distance of 481 miles over the open sea, and with repeating the performance to strike Lord Howe Island, five miles in area, after a flight of 561 miles on the second stage of his journey.

Shown is the chart showing the plotting of the flight from Norfork Island to Lord Howe Island. Winds used for dead-reckoning were calculated from drift observations taken on three headings at half-hour intervals: astronomical position lines were obtained by means of sextant observations to correct the errors in dead-reckoning and those of the compass. To make good his landfall the pilot deliberately set course for a position well to the right of his objective. He then pre-computed an altitude of the sun which would correspond with a position line passing through his destination. When a sextant altitude of the correct value was observed, he turned left and flew down the position line until he sighted the island.

The significance of this flight lies in the fact that on two separate occasions the pilot placed complete confidence in his skill in the use of sextant altitudes to navigate, while manually flying the aircraft, to a small island situated far from the nearest land. In each case it would have been impossible for him to reach an alternative destination had he failed to find his objective.

In recognition of this achievement the Guild of Air Pilots and Navigators of the British Empire awarded Francis Chichester the JOHNSTON MEMORIAL NAVIGATION TROPHY for the Year 1931, the first year of its presentation.

The aircraft in which this flight was made later crashed in Japan. The exhibit includes the compass, which was later salvaged, and a Bygrave Slide Rule used by Chichester on his famous flight.

378. POLAR FLIGHTS OF LANCASTER "ARIES". In May 1945 Lancaster "Aries" of the Empire Air Navigation School, captained by Wing Commander D. C. McKinley, D.F.C. made a series of flights over the Arctic Circle, including a flight to the North Pole. These flights were made to test R.A.F. navigation methods and investigate the behaviour of navigation instruments in polar regions. Magnetic investigations were also carried out near the North Magnetc Pole. The display includes photographs taken during the flight and sections of the navigator's log and plotting chart.

RADIO IN AIR NAVIGATION

In the early days, the air navigator was able to apply radio methods that had already been developed for the mariner, but in recent years, because of the more exacting demands of the air, the position has tended to reverse itself, and techniques developed for the air have been applied to marine navigation.

THE TREND OF PRESENT DEVELOPMENTS. The development of accurate and reliable radio aids greatly simplifies the task of the navigator, and one trend today is to present the information given by the radio directly to the pilot in such a form that he can fly according to a precise time schedule; "classical" navigation thus becomes unnesessary. A further development along this line is to couple the radio receiver to the automatic pilot, so that the navigation of the aircraft along a preselected route is automatically ensured. This was achieved in the automatic flight of an American Skymaster across the Atlantic in September, 1947. Another possibility is that the navigation may be taken out of the aircraft and done on the ground. Ground radio equipments are not restricted by weight and size as are airborne sets, so that it is easier to build

accurate and reliable ground equipment. Early in the war primary search radar was used for the purpose when, by means of Ground Controlled Interception equipment, fighter aircraft were directed to within striking distance of enemy planes; the method was found invaluable in countering night raids. Similar equipment is installed at some of the major aerodromes. Together with equipment to identify individual aircraft, it will enable aircraft waiting to land in bad weather to be manoevered into the right position for landing in rapid succession. Further, with G.C.A. equipment, aircraft on the final approach for landing can be directed from the ground so as to maintain the correct track and the correct rate of descent.

RADIO DIRECTION FINDING. When Aircraft began to carry radio transmitters and receivers, simple direction finding apparatus came into use. Modern equipment works automatically, and shows continuously on a dial in the aircraft its bearing from a chosen beacon.

380. MARCONI TYPE AD1 AIRCRAFT TRANSMITTER AND TYPE AD3 RECEIVER. This transmitter and receiver, one of the earliest communication equipments ever produced for civil aircraft, was first introduced in 1920.

381. THE MARCONATOR. The Marconator combines in one instrument the D/F bearing of a chosen ground station and a gyro-magnetic compass repeater reading. The navigator can therefore obtain a true bearing in one operation. A drift scale is provided so that the aircraft may be "homed" directly to the ground station.

382. MURPHY M/F D/F RECEIVER TYPE M.R.70. This modern light weight receiver is designed for use in small and medium sized aircraft. D/F bearings can be obtained by using a small loop, rotated by means of a flexible drive. A continuous visual indication is provided for "homing" to a station.

383. MARCONI AUTOMATIC DIRECTION FINDER, TYPE AD7092. This fully automatic aircraft direction finder gives continuous visual indication of the bearing of any ground station in the medium frequency band to which it is tuned. It is one of the smallest and lightest equipments of its kind, the all-up weight of a typical installation being 35 lbs.

RADIO BEAMS

It is possible so to transmit radio waves that only in a few sharply defined directions can a clear signal be received. These directions define a number of distinct tracks to or from a beacon, and the pilot of an aircraft, equipped with a suitable receiver, can keep a chosen track.

An early application of the beam principle was the Radio Range, widely used in America to mark a system of airways across the country. These were laid out to control the flow of air traffic and to increase safety in the air by reducing the risk of collision at busy centres. The Radio Range is a medium frequency radio beacon which lays down a number of radio beams, generally four, in predetermined directions. The positions of the beams are defined by signals which may be heard on the aircraft's receiver. When flying in a beam the pilot hears a continuous note. Outside the beams a repeated A or N signal in Morse code is heard, depending on which side of a beam the aircraft is flying.

Radio Range Beacons are normally erected near aerodromes or at intersections of busy air routes and the beams are directed along the routes. They

can be used as track guides by aircraft descending below the clouds preparatory to landing at an aerodrome in bad weather. The principal air routes of the U.S.A. are marked by Radio Ranges.

Another application was for blind approach; aircraft cannot descend below low cloud prior to landing unless the pilot is sure of his position within close limits. An early method, still used, was for a ground station to take bearings of the aircraft and to guide it down, along a safe path, by instructions over the radio. A radio beam can be used for the same purpose. If it is in line with the runway, the pilot can, by keeping in the beam, break cloud, and be in a right position for landing. In the latest type of blind approach equipment, an inclined path for descent at a predetermined rate is provided in addition to the directional beam. By keeping on this glide path and on the beam, the pilot can control his approach almost to the point of touch-down.

The exhibit includes a map showing the positions of Radio Range stations in the New York area, and a chart showing a procedure for descending through cloud using this system.

384. Standard beam approach, s.b.a. A high frequency radio aid used in making an approach to land in bad visibility. It uses an aural pattern similar to the Radio Range. an addition to the beam there are two marker beacons for the pilot to check his distance from the runway during the approach, and accordingly to adjust his rate of descent. S.B.A. is fitted at all important aerodromes in the United Kingdom. A map shows S.B.A. installations in Southern England, and a schematic diagram and chart illustrate the type of procedure followed in making a landing approach using the system.

385. Marconi beam approach receiver, type ad 86. The receiver is used by aircraft making an approach prior to landing. Used with the S.B.A. system, it combines both course and marker receivers in one unit. An example of contact modern radio equipment, it is less than one quarter the weight and size of more conventional apparatus.

386. Instrument landing system, i.l.s. A beam approach system. The ground transmitters produce two radio beams on very high frequency, one defining the direction of approach for landing in a similar manner to S.B.A.; the other defining the glide path at a predetermined slope. I.L.S. provides visual indications on a dial in the form of two crossed pointers. By maintaining these pointers in the centre of the dial, the pilot is able to guide his aircraft down an accurately predetermined line until he is within visual distance of the runway. There are three marker beacons to enable the pilot to check his distance from the runway. I.L.S. originally developed in U.S.A. as S.C.S.51, is installed at international airports in the United Kingdom and is now being manufactured in this country. The exhibit includes an aircraft receiver and an indicator unit, explanatory schematic diagrams, and a landing chart showing a typical approach procedure.

SPACE PATTERN SYSTEMS

At the beginning of the last war radio aids to air navigation were either of the direction finding or of the beam type. Both types were of limited value for military operations, where an accurate knowledge of the aircraft's position is required at all times, and new forms of radio aid were developed to meet the need. One development was to broadcast a permanent radio pattern in such a way that accurate postion lines could be obtained anywhere within

range of the ground stations: two independent position lines define completely the position of the aircraft. The hyperbolic systems of navigation, of which Gee was the first, are examples of this radio space-pattern principle. Consol (the German Sonne) is another. Consol beacons radiate a pattern which varies continuously with the bearing of the aircraft from the station. A navigator is able to determine his bearing from the beacon by observing the pattern.

387. GEE RECEIVER MK. III. In this system a master station and three "slave" stations, at some distance apart from each other, transmit a series of radio pulses at the same frequency. By measuring the time difference between the arrival of a pulse from the master and any one of the slaves, the airborne set is able to locate the aircraft on one of a system of hyperbolic position lines between these two stations. As the airborne receiver is able to measure such a time interval with respect to two of the slaves simultaneously, it defines the aircraft's position by two intersecting hyperbolae. A cathode ray oscillascope is used to measure the short time intervals concerned and a 'lattice chart' on which the hyperbolae are overprinted is used to interpret the readings.

The exhibit includes a Gee lattice chart, and maps showing existing coverage and explaining the latest development in Gee track guides.

388. LORAN. Loran is an American development of the Gee principle working on a lower frequency to provide greater range. In this system the airborne receiver works one pair of stations at a time to give a hyperbolic position line. And it is not possible to obtain an instantaneous "fix". However, by obtaining two such position lines, and allowing for the motion of the aircraft in the interval, the navigator is able to fix his position.

The Loran receiver is similar in general appearance to the Gee receiver. A chart overprinted with the Loran lattice is shown.

389. DECCA. The Decca Navigator System, first used on D-day 1944 by the Royal Navy, is a medium and short range radio navigational aid using hyperbolic principles for position fixing. Low frequency continuous wave signals are transmitted from a chain of ground stations, and by a method of phase comparison are interpreted in the receiver carried in the aircraft as a position fix in terms of Decca co-ordinates which, transferred directly on to a chart bearing the Decca lattice, gives a geographical fix of high accuracy. The system is fully automatic and very simple, continuous position information being provided on meter indicators. The present coverage of the system extends over much of North and Western Europe. It has no height/range restrictions, and may be used by any number of aircraft fitted with receivers.

The exhibit includes a Decca Mk. VI Air Receiver, Decometer indicators, a specimen chart, and a Decca Flight Plotter, used to interpret Decca readings to maintain an accurately predetermined track.

390. MARCONI CONSOL. This long range medium frequency aid is capable of giving accurate bearings over wide sectors, and can be used with the normal communication and direction finding receivers fitted in ships and aircraft. The model exhibited shows a Consol transmitting station and illustrates the way the characteristic pattern of dots and dashes is radiated.

PRIMARY RADAR. Valuable as the space pattern principle is, it could not give much help in operations far over enemy territory, since it was dependent on ground transmitting apparatus, which had of necessity to be situated in friendly territory. The solution was found in equipment completely contained in the

aircraft, which enables the navigator to "see" the ground through darkness and in cloud Primary radar is based on the "echo sounding" principle, which had already been successfully applied in the detection of enemy aircraft, both from the ground and from our own night fighter aircraft, as well as in Coastal Command anti-submarine operations. The navigation equipment, called H2S, displays on a screen in front of the navigator a picture of the salient features of the ground beneath the aircraft.

This particular apparatus is too heavy and expensive to be suitable for civil aircraft, but the same principle is used in equipment being developed to warn pilots of dangerous cloud or high ground ahead. "Echo sounding" is also used in radio altimeters, which indicate the true height of the aircraft above the ground.

392. Ekco cloud and collision warning equipment. This radar equipment for aircraft enables the navigator to detect cumulo-nimbus clouds and hence storm areas up to 40 miles distant, and so to select a safe route at night in poor visibility. Hills, cliffs, etc. can also be "seen" up to 40 miles; low beaches up to 20 miles, and other aircraft at from 5 to 12 miles.

The equipment is a primary radar; that is, a train of radio pulses is sent out and reflected by clouds, high ground, or other aircraft. It is possible to distinguish these by the nature of the echoes returned.

393. Radar altimeter s.cr 718. This instrument is used to measure the height of the aircraft above the ground. A radio pulse is transmitted downwards and reflected by the ground back to the aircraft. In the receiver the time interval between the outgoing and the returning pulse is measured; this is proportional to, and therefore a measure of, the height of the aircraft. The two pulses are shown on a circular scale round the face of a cathode ray tube. The outgoing pulse is adjusted to coincide with the zero of the scale; the aircraft height is read opposite the second (returning) pulse. In this particular instrument one revolution of the scale is equal to 5,000 feet. Heights can be read to within about 20 feet.

SECONDARY RADAR

By placing a beacon on the ground, to amplify the radio pulse before returning it to a primary radar in the aircraft, the effective range is increased and the beacon served to identify a precise point on the ground. One such beacon in use during the war was called by the code name of Eureka; it was used in conjunction with an airborne set called Rebecca, which was also capable of measuring the approximate bearing of the beacon from the aircraft. A more recent application of the same principle is called simply Distance Measuring Equipment (D.M.E.).

Because of the great accuracy of radio measurement of distance, the same method was used (but with the complicated transmitter-receiver on the ground and the responder in the aircraft) to control special bombing operations, where great precision was required. In this form it was known as Oboe.

With the introduction of such beacons it is now becoming possible for an aircraft to determine both its bearing and its distance from a given point on the ground.

394. Rebecca, mk. iv. Rebecca Mk. IV is a lightweight airborne interrogator operating on very high frequency. It can be used to provide heading and

distance indication with respect to a ground or airborne responder beacon such as Eureka.

395. EUREKA, MK. IV. This is a model of a Eureka beacon of the latest type, approximately one eighth actual size. It is for use in conjunction with Rebecca airborne equipment, from which its distance is measured. This beacon can be remotely controlled over landlines; an alarm signal indicates at the control point any failure of the system.

396. AIR INTERCEPTION FOR FLIGHT REFUELLING. This exhibit shows a special application of the Rebecca/Eureka system. A series of diagrams illustrate how an air interception is effected to refuel an aircraft in flight. The tanker aircraft is fitted with Rebecca and the receiving aircraft is fitted with a special Eureka beacon.

397. GROUND CONTROL APPROACH, G.C.A. G.C.A. is a radar system to assist the pilot of an aircraft to make a safe approach for landing in poor visibility. Two high precision primary radar sets in a trailer on the aerodrome, close to the touch-down point, inform a controller, on the ground, of the position of the aircraft so that he can give the pilot instructions, by radio-telephone, to bring the aircraft into position for a visual landing. The original development was in the U.S.A., and American equipment has been operated at R.A.F. and civil aerodromes in this country with considerable success.

398. BRITISH GROUND CONTROLLED APPROACH EQUIPMENT. A British equipment now under development will provide a display for the controller in the control tower, and not in the radar vehicle as in the American system. By means of a radio link, the equipment in the vehicle will be operated by remote control from the tower. The British equipment is shown in the form of a model vehicle and display console, and a drawing shows how the equipment will be operated. Two charts provide important design details.

399. AIR FIELD SURFACE MOVEMENT INDICATOR. A primary radar system to assist the control of movements of aircraft on the ground, this provides a radar "picture" of the aerodrome in plan on a Plan Position Indicator (cathode ray tube). It consists essentially of a large rotating "scanner" aerial mounted at a suitable vantage point on or near the airfield and a P.P.I. display in the control tower. High discrimination can be obtained and the scanner and display can be seperated by considerable distance. If desired, the P.P.I. presentation can be off-centred to provide a plan presentation of the airfield about the control tower.

400. NAVIGATION OF THE AIR LIFT.

THE NEW EMPHASIS IN AIR NAVIGATION

With the development of these improved aids to navigation, the classical problem of the air navigator, to make good his destination by the most expeditious route, has largely been solved. With the volume of air traffic operating with regularity under increasingly worse visibility conditions, the emphasis of the problem of air navigation has shifted from long-range back to short-range (at which no problem was considered to exist in the early days of flying). The problem has become a problem of safe separation and expeditious flow along busy airways and through main air terminals; in short, it has become a traffic problem. The solution of this problem is one of the challenges facing aviation to-day. The seperation of aircraft manoeuvring within a confined space calls for greater and greater precision in navigational radio. Moreover it is a group

problem, and its solution must be based on the lowest navigational accuracy attainable by the least equipped aircraft operating within the area concerned.

We have seen that aeronautical radio, on which the future of air navigation depends, has of recent years developed along several different paths, and many different systems have been produced. Since the ultimate potentialities of these many aids have not been fully exploited, it is tenable that each should continue in operational use until a satisfactory system, covering all stages of navigation, can be worked out and adopted universally. But the variety of these aids—involving, as they do, different airborne equipment, different training of crews, and in the case of approach aids, different manoeuvring procedures at terminals—is one of the obstacles to the solution of the traffic problem. This is because a fundamental of any traffic flow system is the acceptance by all users of the traffic lanes of a common highway code, conforming with a universal plan. The success of the Radio Range system, despite the fact that it is an obsolescent equipment produced many years before the war, is due to the fact that it imposes common procedures on all users of air space, both on airways and in terminals. At some stage, therefore, it may be necessary to settle on a common system of navigation, both en-route and in the approach to landing—a system about which an orderly flow of traffic may be built up.

The problem facing aviation to-day is to decide whether the improvement in the flow of air traffic that can be achieved by universal adoption of a common system of navigation for each stage of flight is great enough to offset the sacrifice of the operational experience which will be necessary to develop an ideal navigation system.

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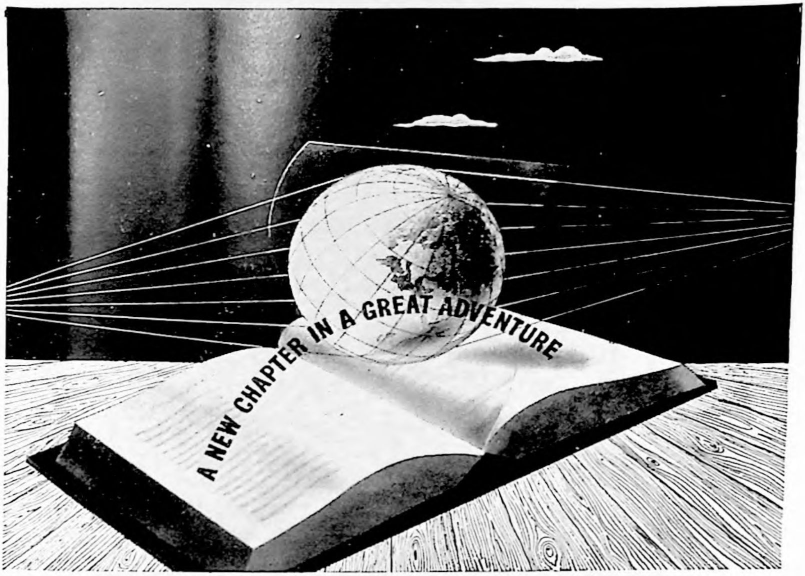

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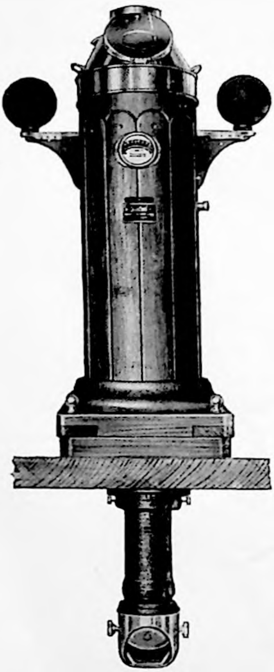

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